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A PRACTICAL COURSE IN BOTANY

WITH ESPECIAL REFERENCE TO ITS BEARINGS ON
AGRICULTURE, ECONOMICS, AND SANITATION

BY

E. F. ANDREWS

AUTHOR OF "BOTANY ALL THE YEAR ROUND"

WITH EDITORIAL REVISION BY

FRANCIS E. LLOYD

PROFESSOR OF BOTANY, ALABAMA POLYTECHNIC INSTITUTE



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ANDREWS'S PR. BOTANY.

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PREFACE

IN preparing the present volume, the aim of the writer has been to meet all the college entrance requirements and at the same time to bring the study of botany into closer touch with the practical business of life by stressing its relations with agriculture, economics, and, in certain of its aspects, with sanitation. While technical language has been avoided so far as the requirements of scientific accuracy will permit, the student is not encouraged to shirk the use of necessary botanical terms, out of a mere superstitious fear of words because they happen to be a little new or unfamiliar. Such a practice not only leads to careless and inaccurate modes of expression, but tends to foster a slovenly habit of mind, and in the long run causes the waste of more time and labor in the search after roundabout, and often misleading, substitutes, than it would require to master the proper use of a few new words and phrases.

In the choice of materials for experiment and illustration, the endeavor has been to call for such only as are familiar and easily obtained. The specimens for flower dissection have been selected mainly from common cultivated kinds, because their wide distribution makes them easy to obtain everywhere, while in cities and large towns they are practically the only specimens available. Another important consideration has been the desire to spare our native wild flowers, or at least not to hasten the extinction with which they are threatened by the ravages of Sunday excursionists and summer tourists, to whose unthinking, but none the less destructive, incursions, the automobile has laid open the most secret haunts of nature. The influence of the public school teacher, and more especially the teacher of botany, is the most potent factor from which we can hope for aid in putting a stop to the relentless persecution that has practically exterminated many of our choicest wild plants and is fast

reducing the civilized world to a depressing monotony of weediness and artificiality. Except for purely systematic and anatomical work, flowers can be studied to better purpose in their living, active state than as dead subjects for dissection; and the best way to show our interest in them, or to get the most rational enjoyment out of them, is not, as a general thing, to cut their heads off and throw them away to wither and die by the roadside. The teacher, by instilling into the minds of the rising generation a reverence for plant life, may do a great deal to aid in the conservation of one of our chief national assets for the gratification of the higher esthetic instincts. The fruits and flowers of cultivation do not stand in the same need of protection, since they are produced solely with a view to the use and pleasure of man, and their propagation is provided for to meet all his demands.

To avoid too frequent interruptions of the subject matter, the experiments are grouped together at the beginning or end of the sections to which they belong, according as they are intended to explain what is coming, or to illustrate what has gone before. A few exceptions are made in cases where the experiment is such an integral part of the subject that it would be meaningless if separated from the context. Under no circumstances should those capable of being performed in the schoolroom be omitted, as much of the information which the book is intended to give is conveyed by their means. For this reason, and also because the aim of the book is to present the science from a practical rather than from an academic point of view, the experiments outlined are for the most part of a simple, practical nature, such as can be performed by the pupils themselves with a moderate expenditure of ingenuity and money. The experience of the writer has been that for the average boy or girl who wishes to get a good general knowledge of the subject, but does not propose to become a specialist in botany, the best results are often obtained by the use of the simplest and most familiar appliances, as in this way attention is not distracted from the experiment itself to the unfamiliar apparatus for making it. In saying this, it is not meant to under-

rate the value of a complete laboratory equipment, but merely to emphasize the fact that the lack of it, while a disadvantage, need not be an insuperable bar to the successful teaching of botany. It is, of course, taken for granted that in schools provided with a suitable laboratory outfit, teachers will be prepared to supplement or to replace the exercises here outlined with such others as in their judgment the subject may demand. There are as many ideals in teaching as there are teachers, and the most that a textbook can do is to present a working model which every teacher is free to modify in accordance with his or her own method.

The writer takes pleasure in acknowledging here the many obligations due to Professor Francis E. Lloyd, of the Botanical Department of the Alabama Polytechnic Institute, at Auburn, Ala., for his valuable aid in the revision of the manuscript, for the highly interesting series of illustrations relating to phototropic movements, and for advice and information on points demanding expert knowledge which have contributed very materially to whatever merit this volume may possess.

Other members of the Auburn faculty to whom the author feels especially indebted are Mr. C. S. Ridgeway, assistant in the Botanical Department, Professor J. E. Duggar, of the Agricultural Department, and Dr. B. B. Ross and Professor C. W. Williamson of the Department of Chemistry. Acknowledgments are due also to Professor George Wood of the Boys' High School, Brooklyn, for suggestions which have been of great assistance in the preparation of this work; to Professor W. R. Dodson, of the University of Louisiana, for illustrative material furnished, and to Professor William Trelease for the loan of original material used in reproducing the beautiful cuts from the Reports of the Missouri Botanical Garden, credit for which is given in the proper place.

E. F. ANDREWS.

AUBURN, ALABAMA.

FULL-PAGE ILLUSTRATIONS

PLATE	PAGE
1. A GROVE OF LIVE OAKS NEAR SAVANNAH, GEORGIA .	<i>Frontispiece</i>
2. CARRYING WATER OVER THE MISSISSIPPI LEVEE BY SIPHON TO IRRIGATE RICE FIELDS	8
3. AËRIAL ROOTS OF A MEXICAN STRANGLING FIG	73
4. A FOREST OF BAMBOO	99
5. A GROUP OF CONIFERS	108
6. A WHITE OAK, SHOWING THE GREAT SPREAD OF BRANCHES .	117
7. A TIMBER TREE SPOILED BY STANDING TOO MUCH ALONE .	125
8. AN AMERICAN ELM, ILLUSTRATING DELIQUESCENT GROWTH .	130
9. VEGETATION OF A MOIST, SHADY RAVINE	151
10. A MOSAIC OF MOONSEED LEAVES	179
11. HYBRID BETWEEN A RED AND A WHITE CARNATION	227
12. GOOSEBERRIES, SHOWING IMPROVEMENT BY SELECTION . .	251
13. THE EFFECTS OF IRRIGATION	272
14. A XEROPHYTE FORMATION OF YUCCAS AND SWITCH PLANTS .	282
15. A GIANT TULIP TREE OF THE SOUTH ATLANTIC FOREST REGION	293

CONTENTS

CHAPTER I. THE SEED

	PAGE
I. THE STORAGE OF FOOD IN SEEDS	1
II. SOME PHYSIOLOGICAL PROPERTIES OF SEEDS	10
III. TYPES OF SEEDS	12
IV. SEED DISPERSAL	21
FIELD WORK	28

CHAPTER II. GERMINATION AND GROWTH

I. PROCESSES ACCOMPANYING GERMINATION	29
II. CONDITIONS OF GERMINATION	33
III. DEVELOPMENT OF THE SEEDLING	40
IV. GROWTH	47
FIELD WORK	52

CHAPTER III. THE ROOT

I. OSMOSIS AND THE ACTION OF THE CELL	53
II. MINERAL NUTRIMENTS ABSORBED BY PLANTS	58
III. STRUCTURE OF THE ROOT	61
IV. THE WORK OF ROOTS	65
V. DIFFERENT FORMS OF ROOTS	72
FIELD WORK	80

CHAPTER IV. THE STEM

I. FORMS AND GROWTH OF STEMS	81
II. MODIFICATIONS OF THE STEM	88
III. STEM STRUCTURE	
A. MONOCOTYLS	96
B. HERBACEOUS DICOTYLS	102
C. WOODY STEMMED DICOTYLS	107

	PAGE
IV. THE WORK OF STEMS	112
V. WOOD STRUCTURE IN ITS RELATION TO INDUSTRIAL USES .	118
VI. FORESTRY	124
FIELD WORK	128

CHAPTER V. BUDS AND BRANCHES

I. MODES OF BRANCHING	131
II. BUDS	138
III. THE BRANCHING OF FLOWER STEMS	141
FIELD WORK	145

CHAPTER VI. THE LEAF

I. THE TYPICAL LEAF AND ITS PARTS	147
II. THE VEINING AND LOBING OF LEAVES	154
III. TRANSPIRATION	160
IV. ANATOMY OF THE LEAF	164
V. FOOD MAKING	168
VI. THE LEAF AN ORGAN OF RESPIRATION	174
VII. THE ADJUSTMENT OF LEAVES TO EXTERNAL RELATIONS .	177
VIII. MODIFIED LEAVES	189
FIELD WORK	194

CHAPTER VII. THE FLOWER

I. DISSECTION OF TYPES WITH SUPERIOR OVARY	196
II. DISSECTION OF TYPES WITH INFERIOR OVARY	204
III. STUDY OF A COMPOSITE FLOWER	210
IV. SPECIALIZED FLOWERS	214
V. FUNCTION AND WORK OF THE FLOWER	219
VI. HYBRIDIZATION	223
VII. PLANT BREEDING	230
VIII. ECOLOGY OF THE FLOWER	
A. THE PREVENTION OF SELF-POLLINATION	235
B. WIND POLLINATION	239
C. INSECT POLLINATION	241
D. PROTECTIVE ADAPTATION	245
FIELD WORK	249

CHAPTER VIII. FRUITS

	PAGE
I. HORTICULTURAL AND BOTANICAL FRUITS	250
II. FLESHY FRUITS	255
III. DRY FRUITS	260
IV. ACCESSORY, AGGREGATE, AND MULTIPLE FRUITS	265
FIELD WORK	269

CHAPTER IX. THE RESPONSE OF THE PLANT TO
ITS SURROUNDINGS

I. ECOLOGICAL FACTORS	271
II. PLANT ASSOCIATIONS	277
III. ZONES OF VEGETATION	288
FIELD WORK	294

CHAPTER X. CRYPTOGRAMS

I. THEIR PLACE IN NATURE	296
II. ALGÆ	299
III. FUNGI	303
A. BACTERIA	306
B. YEASTS	314
C. RUSTS	317
D. MUSHROOMS	323
IV. LICHENS	329
V. LIVERWORTS	334
VI. MOSSES	341
VII. FERN PLANTS	344
VIII. THE RELATION BETWEEN CRYPTOGRAMS AND SEED PLANTS .	354
IX. THE COURSE OF PLANT EVOLUTION	359
FIELD WORK	362

APPENDIX

1. SYSTEMATIC BOTANY	364
2. WEIGHTS, MEASURES, AND TEMPERATURES	367



PLATE 1. — Live oaks covered with Spanish moss (*Tillandsia*).

CHAPTER I. THE SEED

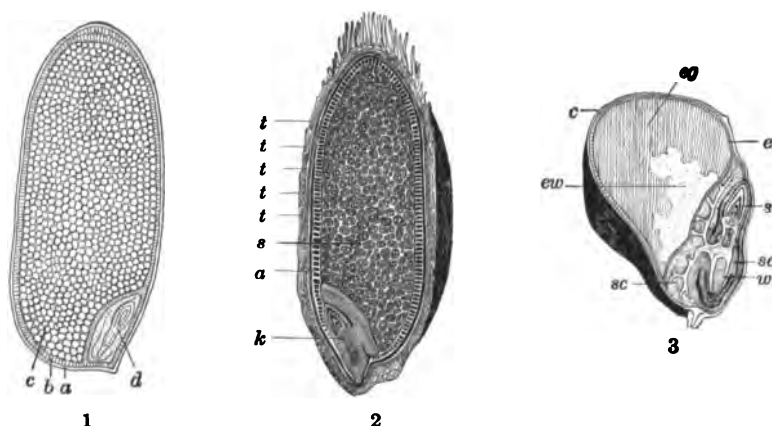
I. THE STORAGE OF FOOD IN SEEDS

MATERIAL. — In addition to the four food tests described in Exps. 1-6, there should be provided some raw starch, a solution of grape sugar, the white of a hard-boiled egg, and any fatty substance, such as lard or oil. For Exps. 8 and 9, a little diastase solution will be necessary. "Taka" diastase, made from rice acted upon by a fungus, can be obtained for a trifle at almost any drug store.

LIVING MATERIAL. — Grains of corn and wheat, and seeds of some kind of bean, the larger the better. The "horse bean" (*Vicia faba*), if it can be obtained, makes an excellent object for study, as the cells are so large that they can be seen with the naked eye. For showing the presence of proteins (aleurone grains) and oily matter, use thin cross sections through the kernel of a castor bean or a Brazil nut. Specimens for the study of the individual cell will be found in the hairs growing on squash seedlings, in the epidermis of one of the inner coats of an onion, in the roots of oat or radish seedlings, or in the section of a young corn root.

A compound microscope will be required for this study.

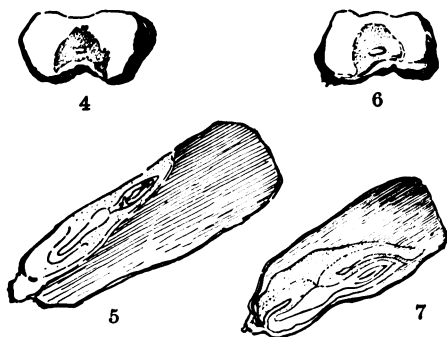
1. The economic importance of seeds. — As a source of food to both man and the lower animals, the importance of seeds can hardly be overrated. All the flour, meal, rice, hominy, and other breadstuffs sold in the market come from them, to say nothing of the fleece from the cotton seed that clothes the greater part of the world, besides furnishing a substitute for lard and an important food for cattle. The oils and fats stored in nuts are also to be taken into account, the peanut alone yielding the greater part of the so-called olive oil of commerce. Since the value of our farm crops depends largely upon the kind and quantity of these substances furnished by them, it is worth our while, as a matter of economic as well as scientific interest, to learn something about the nature of the different foods contained in plants.



FIGS. 1-3.—The world's three most important food grains (magnified): 1, section of a rice grain; *a*, cuticle; *b*, aleurone, or protein layer; *c*, starch cells; *d*, germ; 2, section of a wheat grain; *k*, germ; *s*, starch; *a*, gluten; *t*, *t*, *t*, layers of the seed coat; 3, section of a grain of corn; *c*, husk; *e*, aleurone layer containing proteins; *eg*, yellowish, horny endosperm, containing proteins and starch; *ew*, lighter starchy endosperm: the darker part below is rich in oil and proteins, and contains the embryo, consisting of the absorbing organ, or *cotyledon*, *sc*; the rudimentary bud, *s*; and the root, *w*. (1, from Circular 77, La. Exp. Station; 2, from Francé; 3, from Sachs.)

2. Why food is stored in seeds.—The one purpose for which plants produce their seed is to give rise to a new generation and so carry on the life of the species. The seed is the nursery, so to speak, in which the germ destined

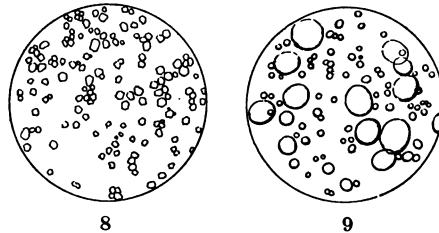
to produce a new plant is sheltered until it is ready to begin an independent existence. But the young plant, like the young animal, is incapable of providing for itself at first, and would die unless it received nourishment from the mother plant until it has formed roots and leaves so that it can manufacture food for



FIGS. 4-7.—Sections of corn grains showing different qualities of food contents: 4, 5, small germ and large proportion of horny part, showing high protein; 6, 7, large germ and smaller proportion of horny part, showing high oil content.

itself. Plants in general require very much the same food that animals do, and they have the power, which animals have not, of manufacturing it out of the crude materials contained in the soil water and in the air. Such of these foods as are not needed for immediate consumption, they store up to serve as a provision for the young shoot when the seed begins to germinate.

3. Food substances contained in seeds.—There are four principal nutriments stored in seeds: *sugars*, *starches*, *oils*, and *proteins*. The first are held in solution and can be detected, if in sufficient quantity, by the taste. The most important varieties of this group are cane and grape sugar, the latter occurring most abundantly in fruits, the former in roots and stems. Oil usually appears in the form of globules. It is very abundant in seeds of the flax, castor bean, and Brazil nut. In the corn grain it is found in the part constituting the germ, or embryo (Figs. 6, 7). Starches and proteins occur in the form of small granules, which have specific shapes in different plants (Figs. 8, 9). Those containing proteins are called *aleurone* grains, and are, as a rule, smaller than the starch grains with which they are intermixed in the bean and some other seeds. In wheat, corn, rice, and most grains they form a layer just inside the husk, as shown in Fig. 10. This is the reason why polished rice and finely bolted flour are less nutritious than the darker kinds, from which this valuable food substance has not been removed. The two most familiar kinds of proteins are the *albumins*, of which the white of an egg is a well-known example, and the *glutins*, which give to the dough of wheat flour and oatmeal their peculiar gummy or "glutinous" structure.



FIGS. 8-9. — Different forms of starch grains :
8, rice ; 9, wheat.

4. Organic foods. — These four substances, starch, sugar, fats, and proteins, with some others of less frequent occurrence, are called *organic foods*, because they are produced, in a state of nature, only through the action of organized living bodies, or, more strictly speaking, of living vegetable bodies.

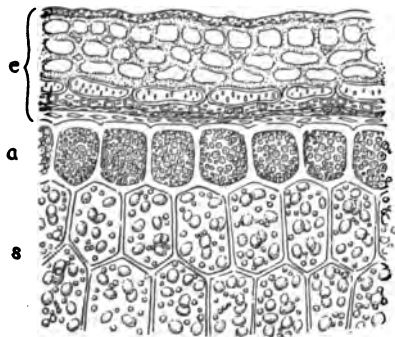


FIG. 10. — Transverse section near the outside of a wheat grain : *e*, the husk ; *a*, cells containing protein granules ; *s*, starch cells (after Tschirch).

5. Our dependence upon plants. — While the animal organism can digest and assimilate these substances after they have been formed by plants, it has no power to manufacture them for

itself, and, so far as we know at present, is wholly dependent upon the vegetable world for these necessities of life. In one sense the whole animal kingdom may be said to be parasitic on plants. The wolf that eats a lamb is getting his food indirectly from the grains and grasses consumed by its victim, and the lion that devours the wolf that ate the lamb is only one step further removed from a vegetable diet.

6. The vegetable cell. — If you will break open a well-soaked horse bean and examine the contents with a lens, you will see that they are composed of small oval or roundish granules packed together like stones in a piece of masonry. These little bodies, called *cells*, are the ultimate units out of which all animal and vegetable structures are built up, as a wall is built of bricks and stones. They differ very much from bricks and stones, however, in that they are, or have been, living structures with their periods of growth, activity, decline, and death, just like other living matter, as will be seen by and by, when we come to look more particularly into their life history. They consist usually of an inclos-

ing membrane which contains a living substance called *protoplasm*. This is the essential part of the cell, and, so far as we know at present, the physical basis of all life. Cells are commonly more or less rounded in shape, though they take different forms according to the purpose they serve. Sometimes, as in the fibers of cotton and the down of young leaves, they are long and hairlike; when closely packed, they often become angular by pressure, like those shown in Figs. 10, 11. The cells composing the thick body of the bean are for the most part starch and other substances stored up for food, which render observation difficult. It will, therefore, be better to choose for a study of the individual cell some kind that will show the essential parts more distinctly.

7. Microscopic examination of a cell.—Place under a high power of the microscope a portion of fresh skin from one of the inside scales of an onion, or a piece of the root tip of a very young corn or oat seedling, and fix your attention on one of the individual cells. Notice (1) the cell wall or inclosing membrane, *w* (Fig. 11); (2) the protoplasm, *p*, which may be recognized by its granular appearance; (3) the *nucleus*, *n*; and (4) the cell sap, *s*. In very young cells the protoplasm will be seen to fill most of the interior; but in mature ones, like the large one on the right of the figure, it forms a thin lining around the wall, with the nucleus on one side, while the cell sap, composed of various substances in solution, occupies the central portion. Though there is generally an inclosing wall, this is not essential, its office being to give strength and mechanical support by holding the contents together, as an India-rubber bag holds water. It is the turgidity of the cell, when distended with liquid, that gives firmness to herbaceous plants and the tender parts of woody ones. This

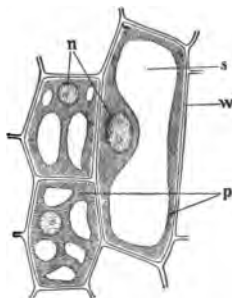


FIG. 11.—Typical cells:
n, nucleus; *p*, protoplasm;
w, cell wall; *s*, sap.

may be illustrated by observing the difference between a rubber bag when quite full and when only half full of water, or a football when partially and when fully inflated. In its simplest form, however, the cell is a mere particle of protoplasm, which has one part, constituting the nucleus, a little more dense in appearance than the rest, but this kind is not common in vegetable structures.

8. How food substances get into the cells. — As there are no openings in the cell walls, the only way substances can get into a cell or out of it is by soaking through the inclosing membrane, as will be explained in a later chapter. Since starch, oil, and proteins, the most important foods stored in seeds, are none of them soluble in the cell sap, it is clear that they could not have got into the cells in their present state, but must have undergone some change by which they were rendered capable of passing through the cell wall.

9. Digestion. — The process by which this change is brought about is known as *digestion*, from its similarity to the same function in animals. Not only are foods, in the state in which we find them stored in the seed, incapable of passing through the cell wall, but the protoplasm, the living part of the cell, has no power to assimilate and to utilize these substances as food until they have been reduced to a soluble form in which they can be diffused freely from cell to cell through any part of the plant. By *diffusion* is meant the gradual spread of soluble substances through the containing medium, as when a lump of sugar or salt, dropped into a glass of water, dissolves and slowly diffuses through the contents, imparting a sweet or salty taste to the whole.

During the process of digestion the different kinds of food are acted upon and made soluble by certain chemical ferments, which are secreted in plants for the purpose. The digestion of starch, the most abundant of plant foods, is effected by diastase, a common ferment obtained from ger-

minating grains of barley, wheat, corn, rice, etc. By the presence of diastase starch is converted into grape sugar, a substance which is readily soluble in water, and which can be diffused easily through the tissues of the plant to any part where it is needed. In this way food travels from the leaf, where it is made, to the seed, where the sugar is generally reconverted into starch and stored up for future use, though sometimes, as in the sugar corn and sugar pea, it remains in part unchanged. The kernels of this kind of corn can be distinguished readily from those of the ordinary starch corn, after maturity, by their wrinkled appearance, owing to their greater loss of water in drying.

10. Food tests.—In order to tell whether any of the food substances named

occur in the seeds that we are going to examine, it will be necessary to understand a few simple tests by which their presence may be recognized. The chemicals required can be ordered ready for use from a druggist or may be prepared in the laboratory as needed, according to the directions given. Write in your notebook a brief account of each experiment made, with the conclusions drawn from it.

EXPERIMENT 1. TO DETECT THE PRESENCE OF FATS.—Rub a small lump of butter or a drop of oil on a piece of thin white paper. What is the effect?

EXPERIMENT 2. ANOTHER TEST FOR FATS.—Place some macerated alcaanna root in a vessel with alcohol enough to cover it, and leave for an hour. Add an equal bulk of water and filter. The solution will stain fats, oils, and resins **deep red**.

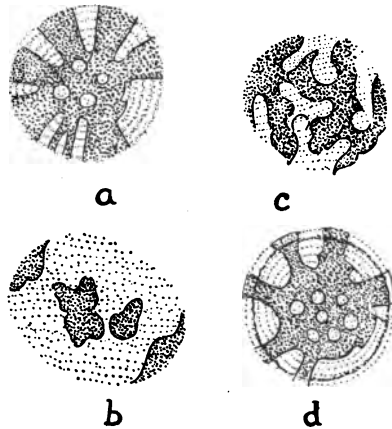


FIG. 12.—Starch grains of wheat in different stages of disintegration under the action of a ferment (diastase), accompanying germination: *a*, slightly corroded; *b*, *c*, and *d*, more advanced stages of decomposition.

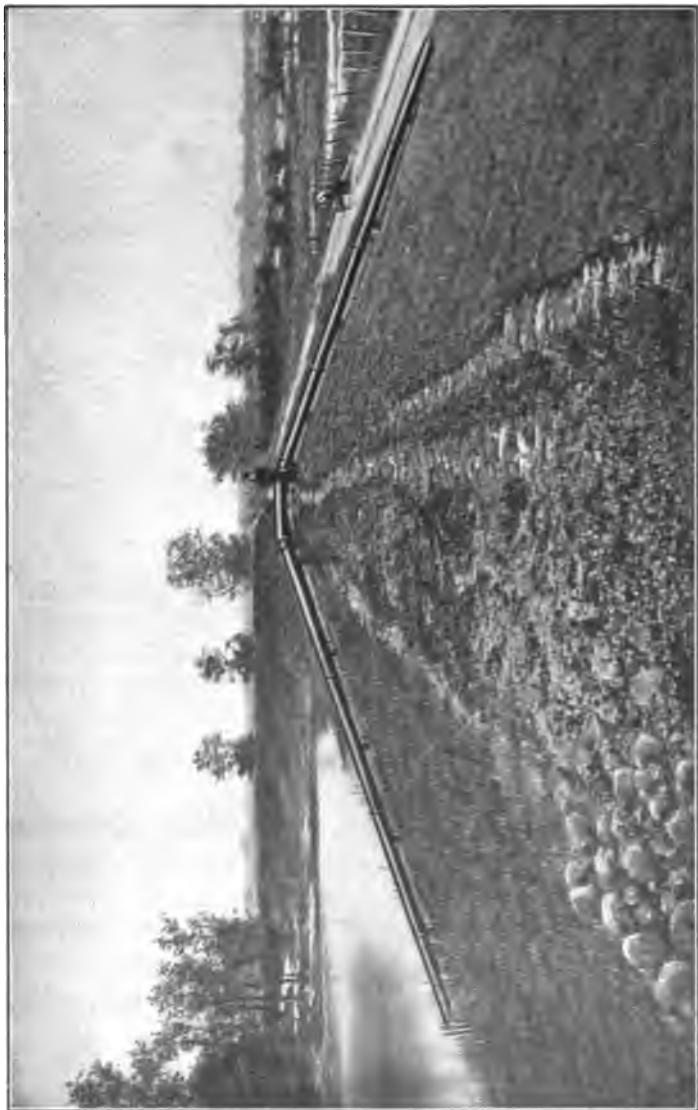


PLATE 2. — Carrying water over the Mississippi levee by siphon to irrigate rice fields. (From Circular of La. Exp. Station.)

EXPERIMENT 3. TO SHOW THE PRESENCE OF STARCH.—Put a drop of iodine solution on some starch. What change of color takes place? To make iodine solution, add to one part of iodine crystals 4 parts potassium iodide and 95 parts water. It should be kept in the dark, as light decomposes it. Iodine colors starch blue, protein substances light brown. In testing for starch, the solution should be diluted till it is of a pale color, otherwise the stain will be so deep as to appear black.

EXPERIMENT 4. A TEST FOR PROTEINS.—Place a small quantity of the white of an egg, diluted with water, in a clean glass and add a few drops of nitric acid; or drop some of the acid on the white of a hard-boiled egg. What is the effect?

Nitric acid turns proteins yellow; if the color is indistinct, add a drop of ammonia, when an orange color will ensue.

EXPERIMENT 5. ANOTHER TEST FOR PROTEINS.—Place on the substance to be examined a drop of a saturated solution of cane sugar and water; add a drop of pure sulphuric acid; if proteins are present, they will be colored red. See also Exp. 3.

EXPERIMENT 6. A TEST FOR GRAPE SUGAR.—Heat a teaspoonful of Fehling's Solution to the boiling point in a test tube (a common glass vial can be used by heating gradually in water) and pour in a few drops of grape sugar solution. Heat again and observe the color of the precipitate that forms.

Fehling's Solution may be obtained of the druggist, or, if preferred, it may be prepared in the laboratory as follows: (a) Dissolve 173 grams of crystallized Rochelle salts and 125 grams of caustic potash in 500 cc. of water; (b) dissolve 34.64 grams crystallized copper sulphate in 500 cc. of water, and mix equal parts as needed. (For English equivalents, see Appendix, Weights and Measures.) The two mixtures must be kept separate till wanted for use, or prepared fresh as needed.

Grape Sugar causes Fehling's Solution to form a red precipitate.

EXPERIMENT 7. TO SHOW THE DIFFERENCE BETWEEN SUGAR AND STARCH IN REGARD TO SOLUBILITY.—Mix some sugar with water and notice how readily it dissolves. Try the same experiment with starch and observe its different behavior.

EXPERIMENT 8. TO SHOW HOW STARCH IS DISINTEGRATED IN THE ACT OF DIGESTION.—Place a few grains of starch on a slide, add a drop or two of diastase solution, and observe under the microscope; the starch granules will be seen to disintegrate and melt away. Even with a hand lens it can be seen, from the greater clearness of the liquid in comparison with a mixture of untreated starch and water, that the grains have been dissolved.

EXPERIMENT 9. TO SHOW THAT DIASTASE CONVERTS STARCH INTO SUGAR. — Make a paste of boiled starch so thin that it looks like water. Pour a small quantity of it into each of two tubes, adding a little diastase to one and leaving the other untreated. Keep in a warm place for twenty-four hours, then test both tubes for starch, as directed in Exp. 3, and note the result. If the diastase has not acted, add a little more and watch.

Practical Questions

1. Name all the food and other economic products you can think of that are derived from the seed of maize; from wheat; from flaxseed; from cotton.
2. Mention some seeds from which medicines are procured.
3. Name all the seeds you can think of from which oil is obtained; starch; some that are rich in proteins. (Exps. 1-5.)
4. Describe some of the ways in which these products are frequently adulterated.
5. If you were raising corn to sell to a starch factory, what part of the seed would you seek to develop? If to feed stock, what part? Why, in each case? (3; Figs. 4-7.)
6. What grain feeds more human beings than does any other?
7. Name all the seeds you can think of that contain sugar in sufficient quantity to be detected without chemical tests; that is, by tasting alone.
8. Is "coal oil" a mineral or an organic substance? Explain, by giving an account of its origin.
9. What is gluten? (3.) Name some grains that are especially rich in it.
10. Which of our three chief food grains is a water plant? (See Plate 2.) Which grows farthest south? Which farthest north? Which one is of American origin?

II. SOME PHYSIOLOGICAL PROPERTIES OF SEEDS

MATERIAL. — Seeds of squash, pumpkin, or other melon; castor bean; any kind of common kidney bean; grains of Indian corn.

APPLIANCES. — In the absence of gas, an alcohol or kerosene lamp may be used for heating. A double boiler can easily be made by using two tin vessels of different sizes. Partly fill the larger one with water, set in it the smaller one with the substance to be heated, and place over a burner. A pair of scales, a strong six-ounce bottle, wire-netting, cord, and wax or paraffin should be provided.

EXPERIMENT 10. DO SEEDS IN THEIR ORDINARY QUIESCENT STATE CONTAIN ANY WATER? — Place a number of beans, or grains of corn or wheat in a glass bottle, making a small perforation in the cork to allow the air to escape, and heat gently. Does any moisture form on the glass?

A better test is to weigh two or three ounces of seeds, and heat them in a double boiler or in oil to prevent scorching. Weigh at intervals. If there is any loss of weight, to what is it due?

EXPERIMENT 11. DO SEEDS ABSORB WATER?—Soak a number of beans or grains of corn in water for 12 to 24 hours and compare with dry ones. What difference do you notice? To what cause is it due?

EXPERIMENT 12. HOW DID WATER GET INTO THE SOAKED SEEDS?—Dry gently with a soft cloth some of the seeds used in the last experiment and press them lightly to see if water comes out, and where. Place a number of dry seeds of different kinds—squash, bean, castor bean, quince, etc.—in warm water and notice whether any bubbles of air form on them and at what point. Examine with a lens and see if this point differs in any way from the rest of the seed cover. Does it correspond with the point from which water exuded in the soaked seeds? Could hard seeds like the squash, castor bean, buckeye, and Brazil nut get water readily without an opening somewhere in the coat?

EXPERIMENT 13. TO FIND OUT WHETHER WATER IS ABSORBED THROUGH THE SEED COATS.—Place in moist sand or sawdust two rows of beans as nearly as possible of the same size and weight, with the eye pressed down to the substratum in one row and turned up in the other, so that no moisture can enter through it. In the same way arrange two rows of castor beans with the little end down in one row and uppermost in the other. In the last set carefully break away the spongy mass near the tip, without injuring the parts about it. Watch and see in which rows water is absorbed most readily. What change takes place in the spongy masses at the tips of those castor beans on which they were left?

EXPERIMENT 14. IS THE RATE OF GERMINATION AFFECTED BY THE PRESENCE OR ABSENCE OF OPENINGS?—Seal up with wax or paraffin all the openings of a number of air-dry peas or beans, and leave an equal number of the same size and weight untreated. Be careful that the sealing is absolutely water-tight, since otherwise the experiment will be worthless. Plant both sets and keep under like conditions of soil, temperature, and moisture. Do you see any difference in the rate of germination of the two sets?

EXPERIMENT 15. DO SEEDS EXERT FORCE IN ABSORBING WATER?—Fill a common six-ounce bottle as full as it will hold with dry peas, beans, or



FIG. 13.—Effect of the expansion of seeds due to absorption of water.

grains of corn; then pour in water till the bottle is full. Tie a piece of wire-netting or stout sackcloth over the top to keep the seeds from being forced out. Bind both the neck and the body of the bottle tightly with strong cords encircling it in both a horizontal and vertical direction, and place under water in a moderately warm temperature. Watch for results.

EXPERIMENT 16. IS THE FORCE EXERTED IN THE LAST EXPERIMENT A MERELY MECHANICAL ONE, LIKE THE BURSTING OF A WATER PIPE, OR IS IT PHYSIOLOGICAL AND THUS DEPENDENT ON THE FACT THAT THE SEEDS ARE ALIVE?—To answer this question try Exp. 15 with seeds that have been killed by heat or by soaking in formalin.

Practical Questions

1. Will a pound of pop corn weigh as much after being popped as before? (Exp. 10.)
2. What causes the difference, if there is any? (Exp. 10.)
3. Does the tuft of downy hairs at the tip of wheat and oat grains influence their water supply? The spongy covering of black walnuts and almonds? The pithy inside layers of pecans and English walnuts? (Exps. 12, 13.)
4. Why will seeds, as a general thing, germinate more readily after being soaked? (Exps. 11, 14, 16.)

III. TYPES OF SEEDS

MATERIAL. — Dry and soaked grains of corn, wheat, or oats; bean, squash, castor bean, and pine seed, or any equivalent specimens showing the differences as to number of cotyledons and the presence or absence of endosperm. Each student should be provided with several specimens, both soaked and dry, of the kind under consideration. Corn, beans, and wheat need to be soaked from 12 to 24 hours; squash and pumpkin from 2 to 5 days, and very hard seeds, like the castor bean and morning-glory, from 5 to 10. If such seeds are *clipped*, before soaking, that is, if a small piece of the coat is chipped away from the end opposite the scar, or eye, they will soften more quickly. Keep them in a warm place with an even temperature till just before they begin to sprout, when the contents become softened. Very brittle cotyledons may be softened quickly by boiling for a few minutes.

No appliances are needed beyond the pupil's individual outfit and some of the food tests given in Section I of this chapter.

II. Dissection of a grain of corn. — Examine a dry grain of corn on both faces. What differences do you notice? Sketch the grooved side, labeling the hard, yellowish outer

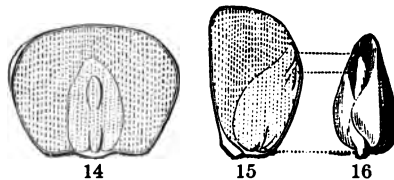
portion, *endosperm*, the depression near the center, *embryo*, or *germ*.

Next take a grain that has been soaked for twenty-four hours. What changes do you see? How do you account for the swelling of the embryo? Remove the skin and observe its texture. Make an enlarged sketch of a grain on the grooved side with the coat removed, labeling the flat oval body embedded in the endosperm, *cotyledon*; the upper end of the little budlike body embedded in the cotyledon, *plumule*, the lower part, *hypocotyl*—words meaning, respectively, “seed leaf,” “little bud,” and “the part under the cotyledon.” As this part has not yet differentiated into root and stem, we cannot call it by either of these names. The cotyledon, hypocotyl, and plumule together compose the embryo. Pick out the embryo and sketch as it appears under the lens.

Crush it on a piece of white paper; what does it contain?

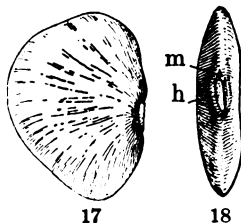
Make a vertical section of another soaked grain at right angles to its broader face, and sketch, labeling the parts as they appear in profile. Make a cross section through the middle of another grain and sketch, labeling the parts as before. What proportion of the grain is endosperm and what embryo? Put a drop of iodine and of nitric acid separately on pieces of the endosperm, and note the effects. Test the seed coats and the cotyledon to see if they contain any starch.

Notice that the corn grain has but one cotyledon, hence such seeds are said to be *monocotyledonous*, or one-cotyledoned. The grains are not typical seeds, but are selected for examination because they are large and easy to handle, can be obtained everywhere, and germinate readily.



FIGS. 14–16. — Dissection of a grain of corn: 14, soaked grain, seen flatwise, cut away a little and slightly enlarged, so as to show the embryo lying in the endosperm; 15, in profile section, dividing the grain through the embryo and cotyledon; 16, the embryo taken out whole. The thick mass is the cotyledon; the narrow body projecting upwards, the plumule; the short projection at the base, the hypocotyl (after GRAY).

12. Dissection of a bean. — Sketch a dry bean as it lies in the pod, showing its point of attachment and any markings that may appear on its surface. Then take it from the pod and examine the narrow edge by which it was attached. Notice the rather large scar (commonly called the eye of the bean)



FIGS. 17, 18. — A kidney bean: 17, side view; 18, front view, showing *h*, hilum, *m*, micropyle.

where it broke away from the point of attachment. This is the *hilum*. Near the hilum, look for a minute round pore like a pinhole. This is called the *micropyle*, from a Greek word meaning “a little gate,” because it is the entrance to the interior of the seed coat. There was no micropyle observed in the corn grain, because it is not a true seed but a fruit inclosing a single seed. The inclosing membrane is the fruit skin, which has become incorporated with the seed coat and taken its place as a protective covering. Compare a soaked bean with a dry one; what difference do you perceive? How do you account for the change in size and hardness? Find the hilum and the micropyle in the soaked bean. Lay it on one side and sketch, with the micropyle on top; then turn toward you the narrow edge that was attached to the pod and sketch, labeling all the parts. Make a section through the long diameter at right angles to the flat sides, press it slightly open, and sketch it. Notice the line or slit that seems to cut the section in half longitudinally, and the small round object between the halves at one end; can you tell what it is?

Slip off the coat from a whole bean and notice its texture. Hold it up to the light and see if it shows any signs of veining. See whether the scar at the hilum extends through the kernel, or marks only the seed coat. Lay open the two flat bodies into which the kernel divides when stripped of its coats, keeping them side by side, with the part above the micropyle toward the top. Sketch their inner face and label

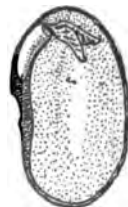


FIG. 19. — Cotyledon of a bean, showing plumule.

them *cotyledons*. Be careful not to break or displace the tiny bud packed away between the cotyledons, just above the hilum. Label the round portion of this bud, *hypocotyl*, and the upper, more expanded part, *plumule*. Which way does the base of the hypocotyl point; toward the micropyle, or away from it? Pick out this budlike body entire and sketch as it appears under the lens. Open the plumule with a pin and examine it with a lens; of what does it appear to consist? Do you find any endosperm around the cotyledons, as in the corn and oats? Break one of the soaked cotyledons, apply the proper tests (Exps. 2, 3, 5), and report what substances it contains. Where is the nourishment for the young plant stored? What part of the bean gives it its value as food?

Notice that in the bean the embryo consists of three parts, the hypocotyl, plumule, and the two cotyledons, which completely fill the seed coats, leaving no place for endosperm. Seeds like the bean, squash, and castor bean, which have two cotyledons, are said to be *dicotyledonous*.

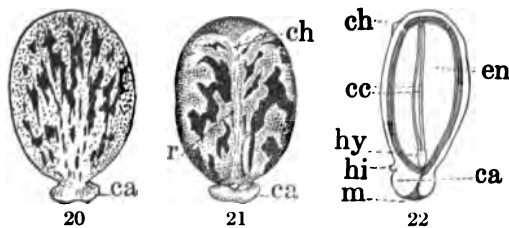
13. The castor bean. — Lay a castor bean on a sheet of paper before you with its flat side down; what does it look like? The resemblance may be increased by soaking the seed a few minutes, in order to swell the two little protuberances at the small end. Can you think of any benefit a plant might derive from this curious resemblance of its seed to an insect?

Sketch the seed as it lies before you, labeling the protuberance at the apex, *caruncle*. The caruncle is an appendage of the seed-covering developed by various plants; its use is not always clear. What appears to be its object in the castor bean? Refer to Exp. 13 and see if there is any other purpose it might serve.

Turn the seed over and sketch the other side. Notice the colored line or stripe that runs from the large end to the caruncle. This is the *rhaphe*, and shows the position that would be occupied by the seed stalk if it were present. Its starting point near the large end, which is marked in fresh

seeds by a slight roughness, is the *chalaza*, or organic base of the seed, where the parts all come together like the parts of a flower at their insertion on the stem. Where was it situated in the common bean? How does this differ from its position in the castor bean? Where the rhaphe ends, just at the beak of the caruncle, you will find the hilum. The micropyle is covered by the caruncle, which is an outgrowth around it.

Now cut a vertical section through a seed that has been soaked for several days, at right angles to the broad sides, and sketch it. Label the white, pasty mass within the seed coats, endosperm. Can you make out what the narrow white line running through the center of the endosperm, dividing it into two halves, represents? Make a similar sketch



FIGS. 20-22. — Castor bean (slightly magnified); 20, back view; 21, front view; *ch*, chalaza; *r*, rhaphe; *ca*, caruncle; 22, vertical section; *en*, endosperm; *cc*, cotyledons; *hy*, hypocotyl; *hi*, hilum; *m*, micropyle.

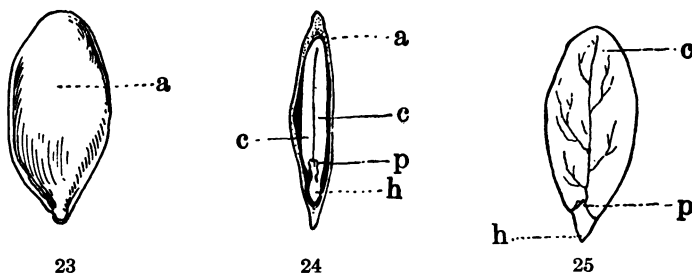
of a cross section. Notice the same white line running horizontally across the endosperm, dividing it into two equal parts. To find out what these lines are, take another seed (always use soaked seeds for

dissection) and remove the coats without injuring the kernel. Split the kernel carefully round the edges, remove half the endosperm, and sketch the other half with the delicate embryo lying on its inner face. You will have no difficulty now in recognizing the lines in your drawings as sections of the thin cotyledons. Where is the hypocotyl, and which way does its base point? Remove the embryo from the endosperm, separate the cotyledons with a pin, hold them up to the light, and observe their beautiful texture. Sketch them under the lens, showing the delicate venation. Is there any plumule?

Test the endosperm with a little iodine. Does it give a

blue or a brown reaction? Crush another bit of it on a piece of white paper and see if it leaves a grease spot. What does this show that it contains? Test the embryo in the same way, and see whether it contains any oil.

NOTE. — It should be borne in mind that the castor bean bears no relation whatever to the true beans. It belongs to the spurge family, which is botanically very remote from that of the peas and beans.



FIGS. 23-25. — Seed of a squash; 23, seed from the outside; 24, vertical section perpendicular to the broad side; 25, section parallel to the broad side, showing inner side of a cotyledon; a, seed coat; c, cotyledons; h, hypocotyl; p, plumule.

14. Study of a squash or gourd seed. — How does the coat of a squash seed differ from that of the bean? At the small end, look for two dots, or pinholes, close together. Refer to your drawing of the bean and see if you can make out, with the help of a lens, what they are. The bean is a curved seed, which is bent so as to bring the hilum close to the micropyle on one side. But by far the greater number of seeds are *inverted*, or turned over on their stalks, as you sometimes see huckleberry blossoms and bell flowers on their stems, so that when the stalk breaks away from its attachment, the scar and the micropyle come close together at one end, as in the squash seed.

Make a drawing of the outside of a seed, labeling all the parts you have observed; then gently

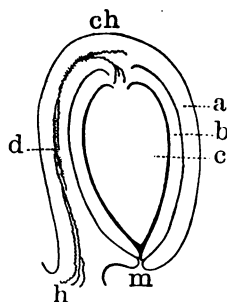
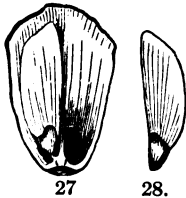


FIG. 26. — Diagram of an inverted or anatropous seed, showing the parts in section: a, outer coat; b, inner coat; c, kernel; d, rhaphe; ch, chalaza; h, hilum; m, micropyle (After GRAY).

remove the hard coat, or *testa*, as it is called. The thin, greenish covering that lines it on the inside is the endosperm. How does it compare in quantity with that in the corn and castor bean? How do the cotyledons compare in thickness with those of the bean? Carefully separate them and draw, labeling the parts as you make them out. The tiny pointed object between the cotyledons at their point of union is the plumule; is it as well developed as in the bean? Can you see any reason why seeds like the pea and bean, which have cotyledons too thick and clumsy to do well the work of true leaves, should have a well-developed plumule, while those with thin cotyledons, like the squash and pumpkin, do not, as a general thing, form a large plumule in the embryo? The little projection in which the cotyledons end is the hypocotyl; which way does it point? Where did you find the micropyle to be? Test the cotyledons and some of the endosperm for food substances; what do you find in them?

15. Study of a pine seed. — Remove one of the scales from a pine cone and sketch the seed as it lies in place on the cone scale. Notice its point of attachment to the scale, and look near this point for a small opening, which you can easily recognize as the micropyle. The seed with its wing looks very much like a fruit of the maple, but differs from it in being a naked seed borne on the inner side of a cone scale, without a pod or husk or outer covering of any kind, such as beans and nuts and grains are provided with. Plants like the pine, which bear their seed in this way, are called



FIGS. 27, 28. — Pitch pine seeds: 27, scale, or open carpel, with one seed in place; 28, winged seed, removed. (After Gray.)

Gymnosperms, a word that means “naked seeds,” in contradistinction to the *Angiosperms*, which bear their seeds in pods or other closed envelopes.

Remove the coat from a seed that has been soaked for twenty-four hours, and examine it with a lens. Does it consist of one or more layers? Is there any difference in color

Remove the coat from a seed that has been soaked for twenty-four hours, and examine it with a lens. Does it consist of one or more layers? Is there any difference in color

between the inner and outer layers? Look at the base of the hypocotyl for some loose, cobwebby appendages. These are the remains of other embryos with certain appendages belonging to them that were formed in the endosperm, but failed to develop. Did you find remains of this kind in any of the other seeds examined? Pick out the embryo from the endosperm and test both for food substances. Which of these do you find? Which are absent? How does the embryo differ from those already examined? How many cotyledons are there? Make an enlarged sketch of a seed in longitudinal section, labeling correctly all the parts observed.

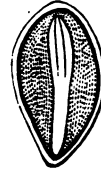


FIG. 29.
— Section of
pine seed,
showing the
polycotyle-
donous em-
bryo (GRAY).

16. Comparison as to food value of seeds. — Make in your notebook a tabular statement after the model here given, of the food contents found in the different seeds you have examined. Indicate the relative quantity of each by writing under it, in the appropriate column, the words, “much,” “little,” or “none,” as the case may be.

By far the greater number of seeds contain endosperm; that is, they consist of an embryo with more or less nourishing

MODEL FOR RECORD OF SEEDS EXAMINED

SEEDS EXAMINED	FOODS TESTED			
	Starch	Sugar	Oil	Proteins
Corn				
Wheat				
Bean				
Squash				
Castor bean . .				
Pine				

matter stored about it. Even in seeds which appear to have none, the endosperm is present at some period during development, but is absorbed by the cotyledons before germination.

17. Manner of storing nourishment. — In the various seeds examined, we have seen that the nourishment for the young plant is either stored in the embryo itself, as in the cotyledons of the bean, acorn, squash, etc., or packed about them in the form of endosperm, as in the corn, wheat, and castor bean.

18. The number of cotyledons. — Seeds are also classed according to the number of their cotyledons, as having one, two, or many cotyledons. The first two kinds make up the great class of Angiosperms, which includes all the true flowering plants and forms the most important part of the vegetation of the globe. The last is characteristic of the great natural division of Gymnosperms, or naked-seeded plants, of which we have had an example in the pine. They are the most primitive type of living seed-bearing plants. Though they are not so abundant now as in past ages, numbering only about four hundred known species, they present many diversities of form, which seem to ally them on the one hand with the lower, or spore-bearing plants (ferns, mosses, etc.), and on the other hand with the Angiosperms.

Practical Questions

1. Make a list of all the seeds you can find that have very thick cotyledons, and underline those that are used as food by man or beast.
2. Make a similar list of all the kinds with thin cotyledons and more or less endosperm, that are used for food or other purposes.
3. Do you find a greater number of foodstuffs among the one kind than the other?
4. How do the two kinds compare, as a general thing, in size and weight?
5. From what part of the castor bean do we get oil? of the peanut? of cotton seed? (Exps. 1-6.)
6. Is there any valid objection to the wholesomeness of peanut oil, and of cottonseed lard as compared with hog's lard? (1, 3.)

7. What is bran? Does it contain any nourishment? (11, 12; Exps. 1-6.)
8. What gives to Indian corn its value as food? to oats? wheat? rice? (3; Exps. 1-6.)
9. Which of these grains has the larger proportion of endosperm to embryo? (Figs. 1-3.)
10. Which contains the larger amount of nutriment in proportion to its bulk, rice or Indian corn?
11. If you wished to produce a variety of corn rich in oil, you would select seed for planting with what part well developed? (3; Figs. 4-7.)

IV. SEED DISPERSAL

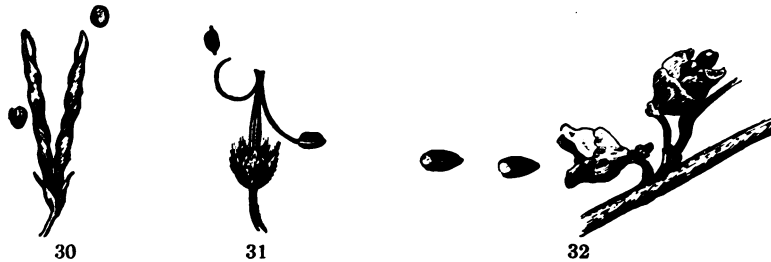
MATERIAL. — Fruits and seeds of any kind that show adaptations for dispersal. Some common examples are: (1) Wind: ash, elm, maple, ailanthus, milkweed, clematis, sycamore, linden, dandelion, thistle, hawkweed. (2) Water: pecan, filbert, cranberry, lotus, hickory nut, coconut — obtain one with the husk on, if possible. (3) Animal agency (involuntary): cocklebur, tickseed, beggar-ticks, burdock; (voluntary) almost all kinds of edible fruits, especially the bright-colored ones — wild plums, cherries, haws, dogwood, persimmons, etc. (4) Explosive and self-planting: witch-hazel, wood sorrel, violet, crane's-bill, wild vetch, peanut, medick, stork's-bill (*Erodium*).

EXPERIMENT 17. TO SHOW HOW SEEDS ARE DISPERSED BY WIND. — Take a number of winged and plumed fruits and seeds, such as those of the maple, ash, ailanthus, dandelion, clematis, milkweed, and trumpet creeper; stand on a chair or table in a place where there is a draft of air and let them all go. Which travel the farther, the winged or the plumed kinds? Which sort is better fitted to aerial transportation?

EXPERIMENT 18. DISPERSAL BY WATER. — Place in a bucket of water a hazelnut, an acorn, an orange, a cranberry, a pecan, a hickory nut, a fresh apple, and a coconut with the husk on. Which are the best floaters? Cut open or break open the good swimmers, compare with the non-floaters, and see to what peculiarity of structure their floating qualities are due. In what situations do the cranberry and the coconut grow? Can you see any advantage to a plant so situated in producing fruits that float easily?

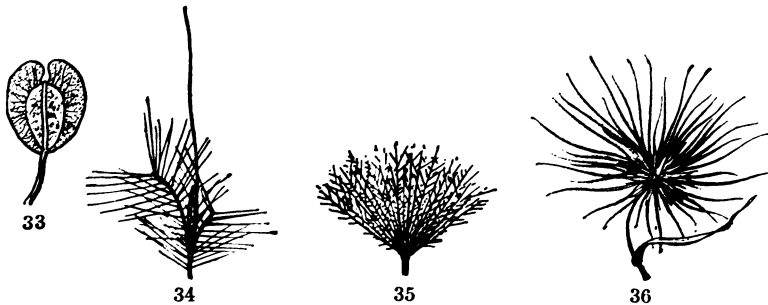
EXPERIMENT 19. DISPERSAL BY EXPLOSIVE CAPSULES. — Moisten slightly some mature but unopened capsules of witch hazel, wood sorrel, rabbit pea, or violet, and leave in a warm, dry place for fifteen to forty-five minutes. What happens when the pods begin to dry? Measure the distance to which the different kinds of seeds have been ejected. Which were thrown farthest? What was the object of the movement? What caused the explosion?

EXPERIMENT 20. THE USE OF ADHESIVE FRUITS. — Scatter broadcast a handful of hooked or prickly seeds or fruits — cocklebur, tickseed, beggarticks, bur grass, etc. Are they suited for wind transportation? Drop one of them on your sleeve, or on the coat of a fellow student; will it stay there? What would be the effect if it became attached to the fur of a roaming animal? Is this a successful mode of dissemination?



FIGS. 30-32. — 30, A pod of wild vetch, with mature valves twisting spirally to discharge the seed; 31, pod of crane's-bill discharging its seed; 32, capsules of witch-hazel exploding.

19. Agencies of dispersal. — The means at nature's disposal for this purpose, as shown by the experiments just made, are four; namely, wind, water, the explosion of capsules due to the withdrawal of water, and the agency of animals, including man. The first three are purely mechanical. The



FIGS. 33-36. — Fruits adapted to wind dispersal: 33, winged pod of pennycress; 34, spikelet of broom sedge; 35, akene of Canada thistle; 36, head of rolling spinifex grass.

last, animal agency, is either voluntary or involuntary, according as it is conscious and intentional, or accidental merely. Man, of course, is the only consciously voluntary agent. Of

the four agencies named, animals and wind are the most effective, and the greater number of adaptations observed will be found to have reference to these.

20. Involuntary dispersal. — The lower animals may be voluntary agents in a way, though not designedly so, as when



FIG. 37.—Good quality of clover seed.



FIG. 38.—Inferior quality of clover seed mixed with "screenings."

a squirrel buries nuts for his own use and then forgets the location of his hoard and leaves them to germinate; or when a jaybird flies off with a pecan in his bill, intending to crack and eat it, but accidentally lets it fall where it will sprout and take root. Both man and the lower animals are not only involuntary, but often unwilling agents of dispersal. Some of the most troublesome weeds of civilization have been unwittingly distributed by man as he journeyed from place to place, carrying, along with the seed for planting his crops, the various weed seeds, or "screenings," as these mixtures are called by dealers, with which they have been adulterated either through carelessness and ignorance, or from unavoidable causes. The neglected animals, also, that are allowed by short-sighted farmers to wander about with their hair full of cocklebur and other

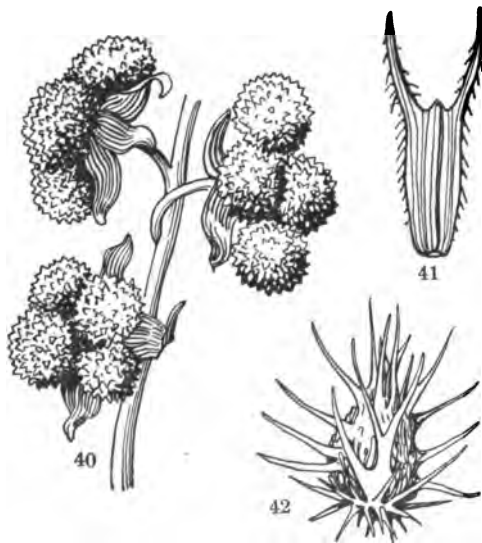


FIG. 39.—Dodder on red clover, showing how the seeds get mixed.

adhesive weed pests, are no doubt very unwilling carriers of those disagreeable burdens.

21. Tempting the appetite. — This is the most important adaptation to dispersal by animals. Have you ever asked yourself how it could profit a plant to tempt birds and beasts to devour its fruit, as so many of the bright berries we find in the autumn woods seem to do? To answer this question, examine the edible fruits of your neighborhood and you will find that almost without exception the seeds are hard and

bony, and either too small to be destroyed by chewing, and thus capable of passing uninjured through the digestive system of an animal; or, if too large to be swallowed whole, compelling the animal, by their hardness or disagreeable flavor, to reject them. In cases where the seeds themselves are edible and attractive, the fruits are usually armed during the growing season with protective coverings,



FIGS. 40-42.—Adhesive fruits : 40, fruit of hound's-tongue ; 41, akene of bur marigold ; 42, fruit of bur grass (cenchrus).

like the bur of the chestnut and the astringent hulls of the hickory nut and walnut. The acidity or other disagreeable qualities of most unripe fruits serves a similar purpose, while their green color, by making them inconspicuous among the foliage leaves, tends still further to insure them against molestation.

22. Voluntary agency. — The cultivated fruits and grains owe their distribution and survival almost entirely to the

voluntary agency of man. Dispersal by this means, whether intentional or accidental, is purely artificial, and except in the case of a few annuals like horseweed, bitterweed, ragweed, goosefoot, and other field pests that have adjusted their season of growth and flowering to the conditions of cultivation, is not correlated with any special modification of the plants for self-propagation. On the contrary, many of the most widely distributed weeds of cultivation, such as the ox-eye daisy, the rib grass, mayweed and bitterweed, possess very imperfect natural means of dispersal, and are largely dependent for their propagation on the involuntary agency of man.

23. Use of the fruit in dispersal. — It will be seen from the foregoing observations that the fruit plays a very important part in the work

of dispersal, most of the adaptations for this purpose being connected with it. In cases where a number of seeds are contained in a large pod that could not conveniently be blown about by the breeze, adaptations for

wind dispersal are attached to the individual seeds, as in the willow, milkweed, trumpet creeper, and paulonia; but as a general thing, adaptations of the seed are for protection, the work of dispersal being provided for by the fruit. In the case of the large class of plants known as "tumbleweeds," the whole plant body is fitted to assist in the work of transportation. Such plants generally grow in light soils and either have very light root systems, or are easily broken from their

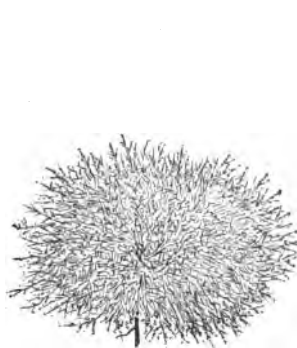


FIG. 43. — A fruiting plant of winged pigweed (*Cycloloma*), showing the bunchy top and weak anchorage of a typical tumbleweed.



FIG. 44. — Panicle of "old witch grass," a common tumbleweed.

anchorage and left to drift about on the ground. The spreading, bushy tops become very light after fruiting, so as to be easily blown about by the wind, dropping their seeds as they go, until they finally get stranded in ditches and fence corners, where they often accumulate in great numbers during the autumn and winter.

24. The advantages of dispersal. — Seed cannot germinate unless they are placed in a suitable location as to soil, moisture, and temperature. In order to increase the chances of securing these conditions, it is clearly to the advantage of a species that its seeds should be dispersed as widely as possible, both that the seedlings may have plenty of room, and that they may not have to draw their nourishment from soil already exhausted by their parents. The farmer recognizes this

principle in the rotation of crops, because he knows that successive growths of the same plant will soon exhaust the soil of the substances required for its nutrition, while they may leave it richer in nourishment for a different crop.



FIG. 45. — Self-planting pod of peanut.

25. Self-planting seeds. — Dispersal is not the only problem the seed has to meet. The majority of seeds cannot germinate well on top of the ground, and must depend on various agencies for getting under the soil. Some of them do this for themselves. The

seeds of the stork's-bill, popularly known as "filarees," have a sharp-pointed base and an auger-shaped appendage at the apex, ending in a projecting arm (the "clock" of the filaree) by which it is blown about by the wind with a whirling motion

till it strikes a soft spot, when it begins at once to bore its way into the ground. The common peanut is another example. The blossoms are borne under the leaves, near the base of the stem, and as soon as the seeds begin to form, the flower stalks lengthen several inches, carrying the young pods down to the ground, where they bore into the soil and ripen their seeds.

Practical Questions

1. Name the ten most troublesome weeds of your neighborhood.
2. What natural means of dispersal have they?
3. Which of them owe their propagation to man?
4. Are there any tumbleweeds in your neighborhood?
5. Would you expect to find such weeds in a hilly or a well-wooded region? (19; Exp. 17.)
6. What situations are best fitted for their propagation? (19, 23; Exp. 17.)
7. Make a list of all the fruits and seeds you can think of that are adapted to dispersal by wind; by water; by animals.
8. By what means of dissemination, or protection, or both, is each of the following distinguished: the squash; apple; fig; pecan; poppy; bean; beggar-tick; linden; grape; rice; pepper; olive; cranberry; jimson weed; thistle; corn; wheat; oats?
9. What is the agent of dispersion, or what the danger to be provided against, in each case?
10. Could our cultivated fruits and grains survive in their present state without the agency of man? (22.)
11. Name all the plants you can think of that bear winged seeds and fruits; are they, as a general thing, tall trees and shrubs, or low herbs?
12. Name all you can think of that bear adhesive seeds and fruits; are they tall trees or low herbs?
13. Give a reason for the difference. (Exps. 17, 20.)
14. Why is the dandelion one of the most widely distributed weeds in the world? (19; Exp. 17.)
15. Is the wool that covers cotton seed for dispersal or protection?
16. What advantage to the Indian shot (canna) is the excessive hardness of its seeds? (21.)
17. What is the use to the species, of the bitter taste of lemon and orange seed? (21.)
18. Why are the seeds of dates and persimmons and haws so hard? (21.)

19. Do you find any edible seeds without protection? If so, account for the want of it. (21, 22.)

20. Name some of the agencies that may assist in covering seeds with earth.

21. Do you know of any seeds that bury themselves?

22. The seeds of weeds and other refuse found mixed with grain sold on the market are known, commercially, as "screenings." Wheat brought to mills in Detroit showed screenings that contained, among other things, seeds of black bindweed, green foxtail grass, yellow foxtail, chess, oats, ragweed, wild mustard, corn cockle, and pigweed. Can you mention some of the ways in which these foreign substances may have gotten into the crop and suggest means for keeping them out?

Field Work

The subjects treated in the foregoing chapter are, in general, better suited to laboratory than to field work. There are some details, however, which can be observed to advantage out of doors. Many of the seeds found in your walks will show peculiarities of shape and external markings and color that will invite observation. Examine also the contents of different kinds you may meet with, as to the presence or absence of endosperm and the arrangement and development of the embryo. Note: (1) whether, as a general thing, there is any difference in size and weight and amount of nourishing matter in the two kinds; (2) the greater variety in the shape and arrangement of the cotyledons in the albuminous kind, and in the arrangement of the embryo; (3) the differences in the development of the plumule in the two kinds, — and give a reason for the facts observed.

Among the different seeds you may find, look for adaptations for dispersal, and decide to what particular method each is suited. Study the agencies by which various kinds may get covered with soil. If the common stork's-bill (*Erodium cicutarium*) grows in your neighborhood, its seeds will well repay a little study, and if there is a field of peanuts within reach, do not fail to pay it a visit.

CHAPTER II. GERMINATION AND GROWTH

I. PROCESSES ACCOMPANYING GERMINATION

MATERIAL. — A pint or two of corn, peas, beans, or any quickly germinating seed.

APPLIANCES. — Matches; wood splinters; gas jet or alcohol lamp; test tubes; a small quantity of mercuric oxide; a thermometer; a couple of two-quart preserve jars, and a smaller wide-mouthed bottle that can be put into one of them; some limewater; a glass tube (the straws used by druggists for soft drinks will answer).

26. Preliminary exercises. — Before taking up the study of germinating seeds, it is important to learn from what sources the organic substances used by the growing plant are derived, and some of the processes that accompany growth and development.

EXPERIMENT 21. TO SHOW THE CHANGES THAT ACCOMPANY OXIDATION. — Strike a match and let it burn out. Examine the burnt portion remaining in your hand; what changes do you notice? These changes have been caused by the union of some substance in the match with something outside of it, in the act of burning; let us see if we can find out what this outside substance is.

EXPERIMENT 22. TO SHOW THE ACTIVE AGENT IN OXIDATION. — Heat some mercuric oxide in a test tube over the flame of a burner. The heat will cause the oxygen to separate from the mercury, and in a short time the tube will be filled with the gas. Extinguish the flame from a lighted splinter and thrust the glowing end into the tube; what happens? The oxygen unites with something in the wood and causes it to burn just as the match did. Compare your burnt splinter with the burnt end of the match; what resemblance do you notice between them?

EXPERIMENT 23. TO SHOW THAT CARBON DIOXIDE IS A PRODUCT OF OXIDATION. — Your experiment with the match showed that ignition is accompanied by heat, and if active enough, by light, and also that it left behind a solid substance in the form of charcoal. But how about the part that united with the oxygen to produce these results?

Let us see what became of it. Hold a lighted candle under the open end of a test tube, or under the mouth of a small glass jar. Does any vapor collect on the inside? After two or three minutes quickly invert the jar or the tube, and thrust in a lighted match: what happens? Can the substance now in the jar be ordinary air? Why not? (Exps. 21, 22.) Pour in a small quantity of limewater, holding your hand over the mouth of the tube to prevent the air from getting in; the gas inside, being heavier than air, will not escape immediately unless agitated. What change do you notice in the limewater?

It has been proved by experiment that the kind of gas formed by the burning candle has the property of turning limewater milky; hence, whenever you see this effect produced in limewater, you may conclude that this gas, known as *carbon dioxide*, is present; and conversely, the presence of carbon dioxide, especially if accompanied by some of the other effects observed, as the giving out of heat and moisture, may be taken as evidence that some process similar to that going on in the burning candle is, or has been, at work.

EXPERIMENT 24. DO THESE EFFECTS ACCOMPANY ANY OF THE LIFE PROCESSES OF ANIMALS? — Blow your breath against the palm of your hand; what sensation do you feel? Blow it against a mirror, or a piece of common glass; what do you see? Blow through a tube into the bottom of a glass containing limewater; how is the water affected? How do these facts correspond with the results of Exp. 23?



FIG. 46. — Diagrammatic section, showing arrangement of jars for Exp. 25.

EXPERIMENT 25. IS THERE ANY EVIDENCE THAT A SIMILAR PROCESS GOES ON IN PLANTS? — (1) Half fill a small, wide-mouthed jar with limewater, place it inside a larger one (Fig. 46), and fill the space between them, up to the neck of the smaller vessel, with well-soaked peas, beans, or barleycorns, on a bed of moist cotton or blotting paper. Cover with a piece of glass and keep at a moderately warm temperature. (2) As a control experiment, place beside this another jar arranged in precisely the same way, except that seeds must be used whose vitality has been destroyed by heat. To prevent the entrance of germs among the dead seeds, which might cause fermentation and thus interfere with the experiment, set the jar containing them in a vessel of water and boil an hour or two before the experiment begins. Otherwise, treat precisely as in (1).

After germination has taken place in (1), what change do you notice in the limewater? If the effect is not apparent, gently stir with a straw or

a glass rod to mix it with the gas in the larger jar. Has the limewater in the control experiment undergone the same change? (It may show a slight milkiness due to the carbon dioxide in the air.) Insert a thermometer among the seeds in both of the larger jars, and compare their temperature with that of the outside air; which shows the greater rise? From this experiment and the last one, what process, common to animals, would you conclude has been going on in the germinating seeds?

NOTE. — Heat in germinating seeds is not always due to this cause alone, but is sometimes increased by the presence of minute organisms called bacteria. Germinating barley and rye in breweries sometimes show an increase in temperature of 40 to 70 degrees, due to these organisms, and spontaneous combustion in seed cotton has been reported from the same cause.

27. Oxidation. — The process that brought about the results observed in the foregoing experiments, and popularly known as *combustion*, is more accurately defined by chemists as *oxidation*. It takes place whenever substances enter into new combinations with oxygen. The most familiar examples of it are when oxygen enters into combination with substances containing carbon. It was the union of a portion of the oxygen of the air in Exp. 21, and of that in the tube in Exp. 22, with some of the carbon in the wood, that caused the burning. The effect was more marked in the second case because the oxygen in the tube was pure, while in the air it is mixed with other substances.

28. Carbon. — The black substance left in your hand after oxidation of the wood in Exps. 21 and 22 is *carbon*. It composes the greater part of most plant bodies, and, in fact, is the most important element in the realm of organic nature. There is not a living thing known, from the smallest microscopic germ to the most gigantic tree in existence, that does not contain carbon as one of its essential constituents.

29. Carbon dioxide. — The gas produced by the burning candle in Exp. 23, by the germinating seeds in Exp. 25, and expelled from your own lungs in Exp. 24, is carbon dioxide. Chemists designate it by the symbol CO_2 , which means that it consists of one part carbon to two parts oxygen. It is an

invariable product wherever the oxidation of substances containing carbon goes on. Heat and moisture are evolved at the same time, and if oxidation is very active, as in Exps. 21 and 22, light also. When the process takes place very slowly, no light is evolved, and so little heat as to be imperceptible without special observation. Hence, oxidation may go on around us and even in our own bodies without our being conscious of the fact.

Carbon dioxide is of prime importance to the well-being of plants. It furnishes the material from which the greater part of their organic food is derived, as will be seen when we take up the study of the leaf and its work. To animals, on the contrary, its presence is so injurious that if the proportion of it in the air we breathe ever rises much above 1 part to 1000, the ill effects become painfully sensible. It is not, however, as was formerly supposed, a poison, the harm it does being to decrease the proportion of oxygen in the atmosphere so that animals cannot get enough of it to breathe, and die of suffocation.

30. Respiration in plants and in animals. — It was shown in Exp. 24 that respiration in animals is accompanied by the products of oxidation; hence we conclude that respiration is a form of oxidation. And since these same products are given off by plants (Exp. 25), the inference is clear that the same process goes on in them. But in plants the life functions are so much more sluggish than in animals that it is only in their most active state, during germination and flowering, that evidence of it is to be looked for.

31. Respiration and energy. — In plants, as in animals, respiration is the expression or measure of energy. Sleeping animals breathe more slowly than waking ones, snakes and tortoises more slowly than hares and hawks. The more we exert ourselves and the more vital force we expend, the harder we breathe; hence, respiration is more active in children than in older persons and in working people than in those at rest. It is the same with plants; respiration is most

perceptible in germinating seeds and young leaves, in buds and flowers, where active work is going on. Hence, in this condition they consume proportionately larger quantities of oxygen and liberate correspondingly larger quantities of carbon dioxide, with a proportionate increase of heat. In some of the arums, — calla lily, Jack-in-the-pulpit, colocasia, etc., — and in large heads of compositæ, like the sunflower, where a great number of small flowers are brought together within the same protecting envelope, the rise of temperature is sometimes so marked that it may be perceived by placing a flower cluster against the cheek.

Practical Questions

1. What is charcoal? (28.)
2. Is any of this substance contained in the seed? in the flour and meal made from seed? (28; Exp. 25.)
3. What combination takes place when the cook lets the stove get too hot and burns the biscuits? (27, 28.)
4. Of what does the burned part consist? (28.) What was it before it was burned? (27, 28.)
5. Which burns the more readily, an oily seed or a starchy one? Which leaves the more solid matter behind? (Suggestion: test by putting a bean, or a large grain of corn, and an equal quantity of the kernel of a Brazil nut on the end of a piece of wire and thrusting into a flame.)
6. Is there any rational ground for the statement that the wooden buildings formerly used on Southern plantations as cotton ginneries were sometimes destroyed through spontaneous combustion due to the heat generated by piles of decaying cotton seed? (Exp. 25, Note.)

II. CONDITIONS OF GERMINATION

MATERIAL. — Several ounces each of various kinds of seed. For the softer kinds, pea, bean, corn, oats, wheat are recommended; for those with harder coverings, squash, castor bean, apple, pear, or, were obtainable, cotton; for still harder kinds, persimmon and date seeds, or the stones of plum and cherry.

APPLIANCES. — 1 dozen common earthenware plates for germinators; 1 dozen two-ounce wide-mouthed bottles; 2 common glass tumblers; clean sand, sawdust, or cotton batting, for bedding; a double boiler; a gas burner, or a lamp stove.

32. Recording observations. — For this purpose a page should be ruled off in the notebook of each student, after the model here given, and the facts brought out by the different experiments set down as observed.

NUMBER OF SEEDS GERMINATED

No. of hours . .		24	48	72	4 d.	5 d.	6 d.	7 d.	8 d.	10 d.	2 w.
No. of vessel . .	1										
No. of vessel . .	2										
No. of vessel . .	3										
No. of vessel . .	4										.
No. of vessel . .	5										
No. of vessel . .	6										

EXPERIMENT 26. CAN SEEDS HAVE TOO MUCH MOISTURE? — Drop a number of dry beans or grains of corn, oats, or other convenient seed, into a vessel with a bedding of cotton or paper that is barely moistened, and an equal number of soaked seeds of the same kind into another vessel with a saturated bedding of the same material. In a third vessel place the same number of soaked seed, covering them partially with water, and in a fourth cover the same number entirely. Label them 1, 2, 3, and 4; keep all together in a warm, even temperature, and observe at intervals of twenty-four hours for a week. What condition as to moisture do you find most favorable to germination? Would seeds germinate in the entire absence of moisture? How do you know?

EXPERIMENT 27. WAS IT THE PRESENCE OF TOO MUCH WATER, OR THE LACK OF AIR CAUSED BY IT, THAT INTERFERED WITH GERMINATION IN THE LAST EXPERIMENT? — To answer this question experimentally is not easy, since it is difficult to obtain a complete vacuum without special appliances. The simplest way is to fill with mercury a glass tube 30 inches long, closed at one end, and invert it over a small vessel — a tea-cup, or an egg cup will answer — containing mercury enough to cover the bottom to a depth of two or three centimeters (see Appendix, Weights and Measures, for English equivalents.) The tube must be supported in such a way that its lower end will dip into the mercury without touching the bottom of the vessel. With a pair of forceps insert under the mouth of the tube two or three seeds that have been well soaked in water deprived of air by previous boiling. Being lighter than mercury, they will float to the top, where there is a complete absence of air while other conditions

favorable to germination are present. Before releasing, they should be well shaken under the mercury to free them from air bubbles, and if the coats are loose fitting so that they can be removed without injury to the parts inclosed in them, they should be slipped off in order to get rid of any imprisoned air they may contain. Additional moisture may be supplied, if necessary, by injecting, by means of a medicine dropper inserted under the mouth of the tube, a drop or two of water that has been previously boiled. Keep in a warm, even temperature, under conditions favorable to germination, and compare the behavior of the seeds with those placed in the different vessels in Exp. 26.

If appliances for this experiment are lacking, a rough approximation can be made by using the seeds of aquatic plants, such as the lotus, water lily, and the so-called Chinese sacred bean, sold in the variety stores, which we know are capable of germinating in the limited amount of air contained in ordinary soil water. Place an equal number of such seeds, of about the same size and weight, on a bedding of common garden soil in two glass tumblers. Fill one vessel a little over half full of ordinary soil water and the other to the same height with water from which the air has been expelled by boiling. Pour over the liquid a film of sweet oil or castor oil, to prevent the access of air, leaving the surface of the water in the other vessel exposed. In which do the seeds come up most freely?

Some seeds, especially those rich in proteins, as peas and beans, will germinate in a vacuum, because oxygen is supplied for a time by the chemical decomposition of substances in their tissues which contain it, but when these are exhausted, respiration ceases and death ensues.

EXPERIMENT 28. DOES THE DEPTH AT WHICH SEEDS ARE PLANTED AFFECT THEIR GERMINATION? — Plant a number of peas or grains of corn at different depths in a wide-mouthed glass jar filled with moist sand, as shown in Fig. 47, the lowest ones at the bottom, the top ones barely covered. Try different kinds of seed and grain, — radish, squash, cotton, or wheat, — and watch them make their way to the surface. Do you notice any difference in this respect between large seed and small ones? Between those with thick cotyledons and thin ones? At what depth do you find, from your recorded observations, that seed germinate best?

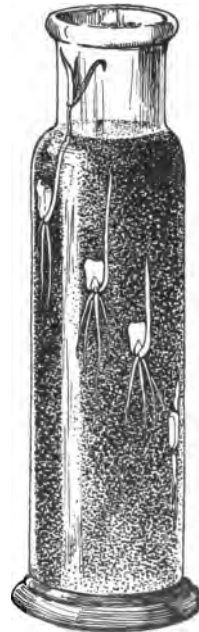
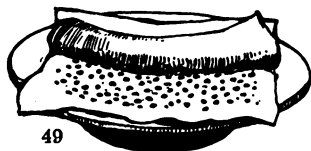


FIG. 47. — To find out the proper depth at which to plant seeds.

EXPERIMENT 29. WHAT TEMPERATURE IS MOST FAVORABLE TO GERMINATION? — Put half a dozen soaked beans on moist cotton or sawdust in three wide-mouthed bottles of the same size or in germinators arranged as



48



49

FIGS. 48, 49. — Home-made germinators: 48, closed; 49, showing interior arrangement.

in Figs. 48, 49, the seed also being selected with a view to similarity of size and weight. Keep one at a freezing temperature; the second in a temperature of 15° to 20° C. (see Appendix for Fahrenheit equivalents); and the third, at 30° C. If a place can be found near a stove or a register, where an even temperature of about 125° F. is maintained, place a fourth receptacle there. Observe at intervals of twenty-four hours for a week or ten days, keeping the temperature as even as possible, and maintaining an equal quantity of moisture in each vessel. Make a daily record of your observations. What temperature do you find most favorable to germination?

EXPERIMENT 30. AT WHAT TEMPERATURE DO SEEDS LOSE THEIR VITALITY? — Place about two dozen each of grains of corn, beans, squash seed, and castor beans, with an equal number of plum or cherry stones, in water, and heat to a temperature of 150° F. After an exposure of ten minutes, take out six of each kind and place in germinators made of two plates with moist sand or damp cloth between them, as shown in Figs. 48, 49. Raise the temperature to 175° F., and after ten minutes take out six more of each kind of seed and place in another germinator. Raise the water in the vessel to 200° , take out another batch of seeds; raise to the boiling point for ten minutes more, and plant the remaining six of each lot. Number the four germinators, and observe at intervals of twenty-four hours for two weeks. The harder kinds should be kept under observation for three or four weeks, as they germinate slowly.

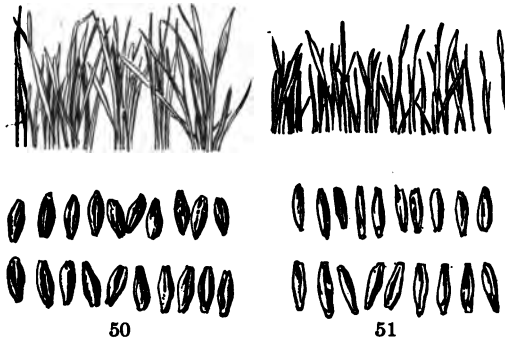
Try the same experiments with the same kinds of seeds at a dry heat, using a double boiler to prevent scorching, and record observations as before.

EXPERIMENT 31. TIME REQUIRED FOR GERMINATION. — Arrange in germinators seeds of various kinds, such as corn, wheat, peas, turnip, apple, orange, grape, castor bean, etc. "Clip" some of the harder ones and keep all the kinds experimented with under similar conditions as to moisture, temperature, etc., and record the time required for each to sprout. What is the effect of clipping, and why?

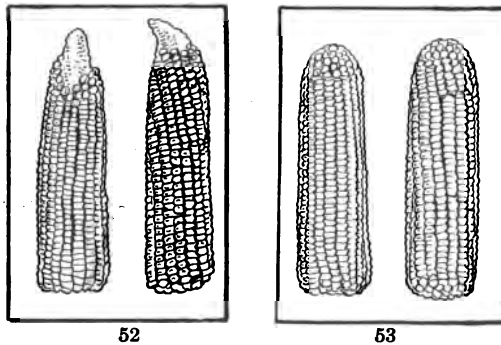
EXPERIMENT 32. ARE VERY YOUNG OR IMMATURE SEEDS CAPABLE OF GERMINATING? — Plant some seeds from half-grown tomatoes, and grains

of wheat, oats, or barley before they are ready for harvesting. Try as many kinds as you like, and see how many will come up. Notice whether there is any difference in the health and vigor of plants raised from seeds in different stages of maturity.

EXPERIMENT 33. THE RELATIVE VALUE OF PERFECT AND INFERIOR SEED. — From a number of seeds of the same species select half a dozen of the largest, heaviest, and most perfect, and an equal number of small, inferior ones. If a pair of scales is at hand, the different sets should be weighed and a record kept for comparison with the seedlings at the end of the experiment. Plant the two sets in pots containing exactly the same kind of soil, and keep under identical conditions as to light, temperature, and moisture. Keep the seedlings under observation for two or three weeks, making daily notes and occasional drawings of the height and size of the stems, and the number of leaves produced by each.



FIGS. 50, 51. — Stem development of seedlings: 50, raised from healthy grains of barley; weight, 39.5 grams (about 500 grs.); 51, raised under exactly similar conditions from the same number of inferior grains; weight, 23 grams (about 350 grs.).



FIGS. 52, 53. — Improvement of corn by selection: 52, original type; 53, improved type developed from it.

33. Resistance to heat and cold.

In making experiments with regard to temperature, notice how the extremes tolerated are influenced, first, by the length of time the seeds are exposed; second, by the amount of water contained in them; and third, by the nature of the seed coats. Every farmer knows that the effect of freezing is much more in-

jurious to plants or parts of plants when full of sap (water) than when dry. This, in the opinion of the most recent investigators, is because the water in the spaces outside the cells freezes first and as moisture is gradually withdrawn from the inside to take its place, the soluble salts which may be present in the cell sap become more concentrated, and by their chemical action on the contained proteins cause them to be precipitated, or "salted out," as we see sugar or salt precipitated from solutions of those substances when water is withdrawn by evaporation. In this way, it is believed, the fundamental protoplasm of the cell may be so disorganized that death ensues if the freezing is continued long enough, since the protein precipitates become "denatured" and cannot be reabsorbed if kept in a solid state too long. The length of time necessary to produce death from this cause is, of course, different in different plants, according to the kind of salts dissolved in the sap and the nature of the proteins acted on by them. The proteins in the sap of *Begonia*, or *Pelargonium*, plants which are very sensitive to cold, yield a denatured precipitate at, or a little below the freezing point of water, while those of winter rye withstand a temperature of $-15^{\circ}\text{C}.$, and of pine needles, $-40^{\circ}\text{C}.$

Mechanical injury through rupture of parts by freezing is not apt to cause serious damage except in cases of sudden and violent cold at a time when the tissues are gorged with sap, as not infrequently happens during the abrupt changes of temperature which sometimes occur in spring after the trees have put forth their leaves. In an extreme case of this kind, the writer has seen the trunk of an oak a foot or more in diameter split in deep seams from the effects of freezing.

34. The length of time during which seeds may retain their vitality. — No direct experiment can be made to test this point, since it would require months, or even years, covering in some instances more than the lifetime of a generation. It has been stated on good authority that seeds of the

water chinquapin (*Nelumbo*) have germinated after more than a hundred years, and moss spores preserved in herbariums, after fifty. But the records in such cases are not always trustworthy, and there is absolutely no foundation for the statements sometimes made about the germination of wheat grains found preserved with mummies over two thousand years old. If kept perfectly dry, however, seed may sometimes be preserved for months, or even years. Peas have been known to sprout after ten years, red clover after twelve, and tobacco after twenty. Ordinarily, however, the vitality of seeds diminishes with age, and in making experiments it is best to select fresh ones. Those used for comparison should also, as far as possible, be of the same size and weight.

35. Effect of precocious germination. — It has been found by experiment that plants raised from immature seed, when they will germinate at all (Exp. 32), yield earlier and larger crops than the same kinds from mature seed. Early tomatoes and some other vegetables are produced in this way. The majority of seeds, however, require a period of rest before beginning their life work. Those that are forced to take up the burden of "child labor" show the effect of such abnormal condition by yielding fruits that are smaller and less firm than those raised from mature seed, so that they do not keep well and have to be marketed quickly. Under what circumstances does it pay to cultivate such fruits?

Practical Questions

1. What are the principal external conditions that affect germination? (Exps. 26-29.)
2. What effect has cold? want of air? too much water?
3. Is light necessary to germination?
4. What is the use of clipping seeds? (Exps. 12, 13, 14, and Material, p. 12.)
5. In what cases should it be resorted to? (Exp. 31.)
6. Why will seed not germinate in hard, sun-baked land without

abundant tillage? Why not on undrained or badly drained land? (Exps. 26, 27.)

7. Will seeds that have lost their vitality swell when soaked? (Exp. 16.)

8. Are there any grounds for the statement that the seeds of plums boiled into jam have sometimes been known to germinate?¹ (33; Exp. 30.)

9. Could such a thing happen in the case of apple or sunflower seed, and why or why not? (33.)

10. Does it make any difference in the health and vigor of a plant whether it is grown from a large and well-developed seed or from a weak and puny one? (Exp. 33.)

11. Would a farmer be wise who should market all his best grain and keep only the inferior for seed?

12. What would be the result of repeated plantings from the worst seed?

13. Of constantly replanting the best and most vigorous?

14. Suppose seed would germinate without moisture; would this be an advantage, or a disadvantage to agriculturists?

15. Why is a cool, dry place best for keeping seeds? (Exps. 26, 29.)

16. Why are the earliest tomatoes found in the market usually smaller than those offered later? (35.)

17. Why is continued rain so injurious to wheat, oats, and other grains before they are mature enough to be harvested? (35; Exp. 32.)

18. Would the same effect be likely to occur in the case of very oily seeds, such as flax and castor beans? Why? (Suggestion: try the effect of putting water on a piece of oiled paper.)

19. Explain why many seeds cannot germinate successfully without air. (30, 31; Exp. 25.)

20. Mention some of the practical advantages that a farmer, a gardener, or a careful housewife might gain from experiments like those made in this section.

21. Explain why seeds can endure so much greater extremes of temperature than growing plants. (23, 33.)

III. DEVELOPMENT OF THE SEEDLING

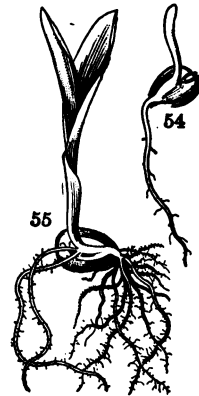
MATERIAL. — Seedlings of various kinds in different stages of growth. It is recommended that the same species be used that were studied in Section III, Chapter I, or such equivalents as may have been substituted for them. Enough should be provided to give each pupil three or four specimens in different stages of development. Seeds, even of the same kind,

¹ Vines, "Lectures on the Physiology of Plants," p. 282. See also Sachs, "Physiology of Plants."

develop at such different rates that it will probably not be necessary to make more than two plantings of each sort, from 2 to 5 days apart. Soaked seeds of corn and wheat will germinate in from 3 to 7 days, according to the temperature; oats in 1 to 4; beans in 4 to 6; squash and castor beans in from 8 to 10. Very obdurate ones may be hastened by clipping. Keep the germinators in an even temperature, at about 70° to 80° F.

Pine is a very difficult seed to germinate, requiring usually from 18 to 21 days. By soaking the mast for twenty-four hours and planting in damp sand or sawdust kept at an even temperature of 23° C. or about 75° F., specimens may be obtained.

36. Seedlings of monocotyls. — Examine a seedling of corn that has just begun to sprout; from which side does the seedling spring, the plain or the grooved one? Refer to your sketch of the dry grain and see if this agrees with the position of the embryo as observed in the seed. Make sketches of four or five seedlings in different stages of advancement, until you reach one with a well-developed blade. From what part of the embryo has each part of the seedling developed? Which part first appeared above ground? Is it straight, or bent in any way? In what direction does the plumule grow? The hypocotyl? Does the cotyledon appear above ground at all? Slip off the husk and see if there is any difference in the size and appearance of the contents as you proceed from the younger to the older plants. How would you account for the difference?



FIGS. 54, 55.—Seedling of corn (after GRAY): 54, early stage of germination; 55, later stage.

37. The root. — Examine the lower end of the hypocotyl and find where the roots originate; would you say that they are an outgrowth from the stem, or the stem from the root? Observe that the root of the corn does not continue to grow in a single main axis like that of the castor bean, but that numerous adventitious and secondary roots spring from

various points near the base of the hypocotyl and spread out in every direction, thus giving rise to the fibrous roots of grains and grasses.

38. Root hairs. — Notice the grains of sand or sawdust that cling to the rootlets of plants grown in a bedding of that kind. Examine with a lens and see if you can account for their presence. Lay the root in water on a bit of glass, hold up to the light and look for root hairs; on what part are they most abundant?



FIG. 56. — Seedling of wheat, with root hairs.

The hairs are the chief agents in absorbing moisture from the soil. They do not last very long, but are constantly dying and being renewed in the younger and tenderer parts of the root. These are usually broken away in tearing the roots from the soil, so that it is not easy to detect the hairs except in seedlings, even with a microscope. In oat, maple, and radish seedlings they are very abundant and clearly visible to the naked eye. The amount of absorbing surface on a root is greatly increased by their presence.

39. The root cap. — Look at the tip of the root through your lens and notice the soft, transparent crescent or horseshoe-shaped mass in which it terminates. This is the root cap and serves to protect the tender parts behind it as the roots burrow their way through the soil. Being soft and yielding, it is not so likely to be injured by the hard substances with which it comes in contact as would be the more compact tissue of the roots. It is composed of loose cells out of which the solid root substance is being formed; the growing point of the root, *g*, is at the extremity of the tip just behind the cap, *c* (Fig. 57). The cap is very apparent in a seedling of corn, and can easily

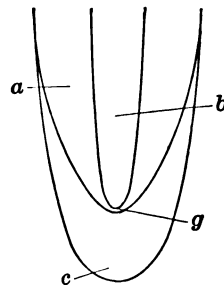


FIG. 57. — Diagrammatic section of a root tip: *a*, cortex; *b*, central cylinder in which the conducting vessels are situated; *c*, root cap; *g*, growing point.

be seen with the naked eye, especially if a thin longitudinal section is made. It is also well seen in the water roots of the common duckweed (*Lemna*), and on those developed by a cutting of the wandering Jew, when placed in water. Are there any hairs on the root cap? Can you account for their absence?

NOTE. — For a minute study of the structure of roots, see 67.

40. Organs of vegetation. — The three parts, root, stem, and leaf, are called organs of vegetation in contradistinction to the flower and fruit, which constitute the organs of reproduction. The former serve to maintain the plant's individual existence, the latter to produce seed for the propagation of the species, so we find that the seed is both the beginning and the end of vegetable life.

41. Definitions.—Organ is a general name for any part of a living thing, whether animal or vegetable, set apart to do a certain work, as the heart for pumping blood, or the stem and leaves of a plant for conveying and digesting sap. By "function" is meant the particular work or office that an organ has to perform.

42. Seedlings of dicotyls. The bean. — Sketch, without removing it, a bean seedling that has just begun to show itself above ground; what part is it that protrudes first? Sketch in succession four or five others in different stages of advancement. Notice how the hypocotyl is arched where it breaks through the soil. Does this occur in the monocotyls examined? Do the cotyledons of the bean appear above ground? How do they get out? Can you perceive any advantage in their being dragged out of the ground backwards in this way rather than pushed up tip foremost?

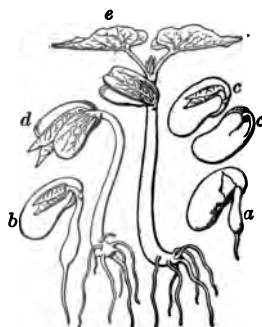


FIG. 58.—Seedlings of bean in different stages of growth: cc, cotyledons, showing the plumule and hypocotyl before germination; a, b, d, and e, successive stages of advancement. At d the arch of the hypocotyl is beginning to straighten; at e it has entirely erected itself.

What changes have the cotyledons undergone in the successive seedlings? Remove from the earth a seedling just beginning to sprout and sketch it. From what point does the hypocotyl protrude through the coats? Does this agree with its position as sketched in your study of the seed? In which part of the embryo does the first growth take place?

Remove in succession the several seedlings you have sketched and note their changes. How does the root differ from that of the corn and oats? The first root formed by the extension of the hypocotyl is the *primary* root and should be so labeled in your drawings; the branches that spring from it are *secondary* roots. Look for root hairs; if there are any, where do they occur?

43. **Germination of the squash.** — How does the manner of breaking through the soil compare with that of the bean?

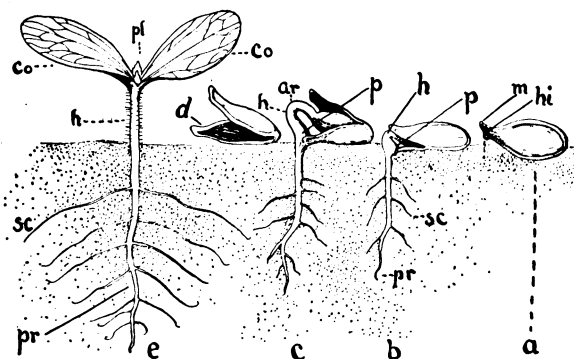


FIG. 59. — Stages in the germination of a typical seedling of the squash family: *a*, a seed before germination; *b*, *c*, *e*, the same in different stages of growth; *d*, the empty testa, with kernel removed; *hi*, hilum; *m*, micropyle; *p*, *p*, the peg in the heel; *h*, *h*, *h*, the hypocotyl; *ar*, arch of the hypocotyl; *co*, cotyledons; *pl*, plumule; *pr*, primary root; *sc*, secondary roots.

With the corn? From which end of the seed, the large or the small one, does the hypocotyl spring? Do the cotyledons come above ground? How do they get out of the seed coat? Notice the thick protuberance developed by the hypocotyl and pressing against the lower half of the coat at the point where the hypocotyl breaks through. This is called the

"peg"; can you tell its use? Could the cotyledons get out of their hard covering without it? Slip the peg below the coat in one of your growing specimens, leave it in the soil, and see what will happen. How do the cotyledons of the squash differ from those of the bean as they come out of the seed cover? Do they act as foliage leaves? Do you see any difference in the development of the plumule in the two seeds (Figs. 19, 25) to account for the different behavior of the cotyledons? Sketch three seedlings in different stages, labeling correctly the parts observed. Make a similar study of the castor bean, or other seedling selected by your teacher, and illustrate by drawings.

44. Arched and straight hypocotyls. — This difference in the manner of getting above ground is an important one. That by means of the arched hypocotyl is, in general, characteristic of the process of germination in which the cotyledons come above ground, while the straight kind, which was illustrated in the corn and wheat, is the prevailing method when the cotyledons remain below ground. Can you give a reason for the difference?

45. Polycotyledons; germination of the pine. — Examine a pine seedling just beginning to sprout. What part emerges first from the seed coat? Where does it break through? Where did you find the micropyle in the pine seed? (15.) Can you give a reason why the hypocotyl in seeds should break through the coats at this point? How do the cotyledons get out of the testa? Is the hypocotyl arched or straight in germination? How does it compare with the bean and squash in this respect? With the corn? Is any endosperm left in the testa after the cotyledons have come out? What has become of it? Do the cotyledons function as leaves? How many of them has the specimen you are studying? Notice the little knob or button

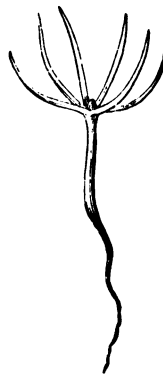


FIG. C0. — Pine seedling (After GRAY).

at the upper end of the hypocotyl, just above the point where the cotyledons are attached; this is the *epicotyl*, or part above the cotyledons, here identical with the plumule; does it develop as rapidly as in the other seedlings you have examined?

46. Relation of parts in the seedling. — Before leaving this subject, it is important to fix clearly in mind the different parts of the germinating seedling and their relation to both the embryo from which they originated and the plant into which they are to develop. The part labeled “hypocotyl” in your sketches is all that portion of the embryo below the point of attachment of the cotyledons. In germination its upper part will become the stem, and in the embryo constitutes the *caulicle*, or stemlet, while its lower part, from which the root will develop, is the *radicle*, or rootlet; hence the term “hypocotyl” includes both the future root and stem. The plumule is that part of the embryo between the cotyledons and *above* their point of attachment to the caulicle. It is the upward growing point of the young plant, and hence the place of attachment of the cotyledon is the first *node*, or point of leaf origin, on the stem.

The epicotyl, in contradistinction to the hypocotyl, is all that part of the plant *above* the insertion of the cotyledons. Before germination it is identical with the plumule. As the seedling grows, the epicotyl advances its growing point by adding new nodes and *internodes*, as the spaces between the successive points of leaf insertion are called.

47. Botanical terms. — As the prefixes *hypo* and *epi* are of frequent occurrence in botanical works, it will aid in understanding their various compounds if you will remember that *hypo* always refers to something below or beneath, and *epi*, to something over or above. With this idea in mind you will see that botanical terms are a labor-saving device, since it is much easier, in making notes, to use a single descriptive word than to write out the long English equivalent, such as “the part under (or over) the cotyledons.”

Practical Questions

1. Do the cotyledons, as a general thing, resemble the mature leaves of the same plants?
2. Name some plants in which you have observed differences, and account for them; could convenience of packing in the seed coats, for instance, or of getting out of them, have any bearing on the matter?
3. Does the position in which seeds are planted in the ground have anything to do with the position of the seedlings as they appear above the surface?
4. Is this fact of any importance to the farmer?
5. Will grain that has begun to germinate make good meal or flour? Why? (27, 36; Exp. 25.)

IV. GROWTH

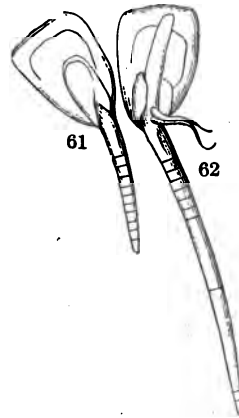
MATERIAL. — Two young potted plants; some lily or hyacinth bulbs; seedlings of different kinds, — some with well-developed taproots, — apple, cotton, and maple are good examples.

APPLIANCES. — A small flat dish, some mercury, and a piece of cork.

EXPERIMENT 34. HOW DOES THE ROOT INCREASE IN LENGTH? — Mark off the root of a very young corn seedling into sections by moistening a piece of sewing thread with indelible ink and applying it to the surface of the root at intervals of about two millimeters ($\frac{1}{16}$ of an inch), or by tying a thread lightly around it at the same intervals. Lay the seedling on a moist bedding between two panes of glass kept apart by a sliver of wood to prevent their injuring the root by pressure. Watch for a day or two, and you will see that growth takes place from a point just back of the tip (Figs. 61, 62).

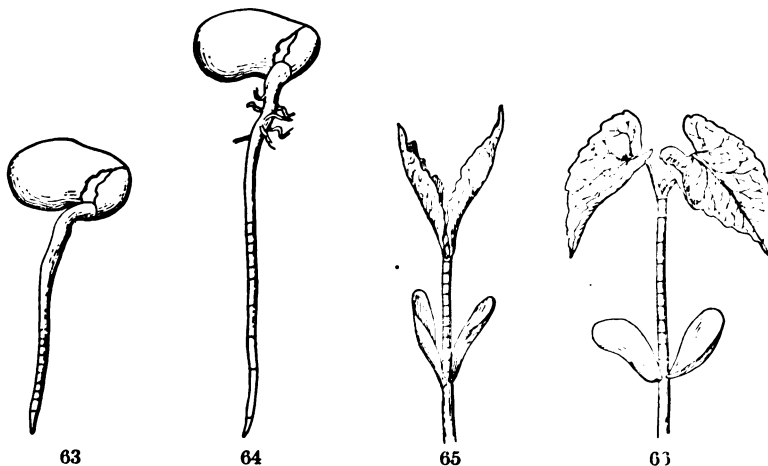
Mark off a seedling of the bean in the same way and watch to see whether it increases in the same manner as the corn.

EXPERIMENT 35. HOW DOES THE STEM INCREASE IN LENGTH? — Mark off a portion of the stem of a bean seedling as explained in the last experiment, and find out how it grows. Allow a seedling to develop until it has put forth several leaves and measure daily the spaces between them. Label these spaces in your drawings, "internodes," and the points where the leaves are attached, "nodes." Does an internode stop growing when the



FIGS. 61, 62. — Seedling of corn, marked to show region of growth: 61, early stage of germination; 62, later stage.

one next above it has formed? When is growth most rapid? Reverse the position of a number of seedlings that have just begun to sprout and watch what will happen. After a few days reverse again and note the effect.

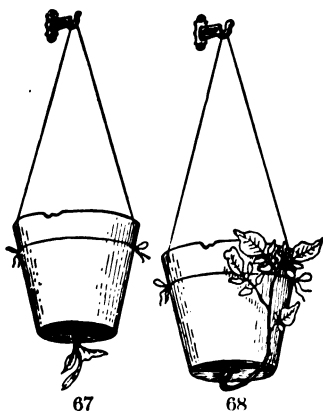


FIGS. 63, 64.—Root of bean seedling, measured to show region of growth: 63, early stage of germination; 64, later stage.

FIGS. 65, 66.—Stem of bean seedling, measured to show region of growth: 65, early stage of growth; 66, later stage.

EXPERIMENT 36. CAN PLANTS GROW AND LOSE WEIGHT AT THE SAME

TIME? — Remove the scales from a white lily bulb, weigh them, and lay in a warm, but not too damp place, away from the light. After a time bulblets will form at the bases of the scales. Weigh them again, and if there has been any loss, account for it. The experiment may be tried by allowing a potato tuber or a hyacinth bulb to germinate without absorbing moisture enough to affect its weight.



FIGS. 67, 68.—Experiment showing the direction of growth in stems: 67, young potato planted in an inverted position; 68, the same after an interval of eight days.

EXPERIMENT 37. IS THE DIRECTION OF GROWTH A MATTER OF ANY IMPORTANCE?

— Plant in a pot suspended as shown in Fig. 67, a healthy seedling of some kind, two or three inches high, so that the plumule shall point downward through the drain hole and the root upward into the soil. Watch the action of the stem

for six or eight days, and sketch it at successive intervals. After the stem has directed itself well upward, invert the pot again, and watch the growth. After a week remove the plant and notice the direction of the root. Sketch it entire, showing the changes in direction of growth.

At the same time that this experiment is arranged, lay another pot with a rapidly growing plant on one side, and every forty-eight hours reverse the position of the pot, laying it on the opposite side. At the end of ten or twelve days remove the plant and examine. How has the growth of root and stem been affected?

What do we learn from these experiments and from Exp. 35 as to the normal direction of growth in these two organs respectively? Can you think of any natural force that might influence this direction?

EXPERIMENT 38. TO SHOW THAT PLANTS WILL EXERT FORCE RATHER THAN CHANGE THEIR DIRECTION OF GROWTH. — Pin a sprouted bean to a cork and fasten the cork to the side of a flat dish, as shown in Fig. 69. Cover the bottom of the dish with mercury at least half an inch deep, and over the mercury pour a layer of water. Cover the whole with a pane of glass to keep the moisture in, and leave for several days. The root will force its way downward into the mercury, although the latter is fourteen times heavier than an equal bulk of the bean root substance, and the root must thus overcome a resistance equal to at least fourteen times its own weight.



FIG. 69. — Experiment showing the root of a seedling forcing its way downward through mercury.

48. What growth is. — With the seedling begins the growth of the plant. Most people understand by this word mere increase in size; but growth is something more than this. It involves a change of form, usually, but not necessarily, accompanied by increase in bulk. Mere mechanical change is not growth, as when we bend or stretch an organ by force, though if it can be kept in the altered position till such position becomes permanent, or as we say in common speech, “till it grows that way,” the change may become growth. To constitute true growth, the change of form must be permanent, and brought about, or maintained, by forces within the plant itself.

49. Conditions of growth. — The internal conditions depend upon the organization of the plant. The essential external conditions are the same as those required for germi-

nation: food material, water, oxygen, and a sufficient degree of warmth. It may be greatly influenced by other circumstances, such as light, gravitation, pressure, and (probably) electricity; but the four first named are the essential conditions without which no growth is possible.

50. Cycle of growth. — When an organ becomes rigid and its form fixed, there is no further growth, but only nutrition and repair, — processes which must not be confounded with it. Every plant and part of a plant has its period of beginning, maximum, decline, and cessation of growth. The cycle may extend over a few hours, as in some of the fungi, or, in the case of large trees, over thousands of years.

51. Geotropism. — The general tendency of the growing axes of plants to take an upward and downward course as shown in Exp. 37 — in other words, to point to and from the center of the earth — is called *geotropism*. It is *positive* when the growing organs point downward, as most primary roots do; *negative* when they point upward, as in most primary stems; and *transverse*, or *lateral*, when they extend horizontally, as is the case with most secondary roots and branches.

52. Gravity and growth. — It cannot be proved directly that geotropism is due to gravity, because it is not possible to remove plants from its influence so as to see how they would behave in its absence. The effect of gravity may be neutralized, however, by arranging a number of sprouting seeds on the vertical disk of a clinostat, an instrument fitted with a clockwork movement by means of which they may be kept revolving steadily for several days. By this constant change of position gravity is made to act on them in all directions alike, which is the same in some respects as if it did not act at all. As the roots, under these circumstances, turn their growing tips toward the axis of motion, without showing a tendency to grow downward, we may conclude that geotropism is a response of the plant to gravity.

53. Geotropism an active force. — It must be noted, however, that the force here alluded to is not the mere me-

chanical effect of gravity, due to weight of parts, as when the bough of a fruit tree is bent under the load of its crop, but a certain stimulus to which the plant reacts by a spontaneous adjustment of its growing parts. In other words, geotropism is an active, not a passive function, and the plant will overcome considerable resistance in response to it. (Exp. 38).

54. Other factors. — The direction of growth is influenced by many other factors, such as light, heat, moisture, contact with other bodies, electricity. The result of all endless variety in the forms organs that seems to defy

Heat, unless excessive, generally stimulates growth; contact sometimes causing the stem to curve away from the disturbing object, and sometimes the stem to curve toward the object by growing more rapidly on

and perhaps by these forces is an and growth of all law.

generally stimulates stimulates it, away from the disturbing object of contact the opposite side,

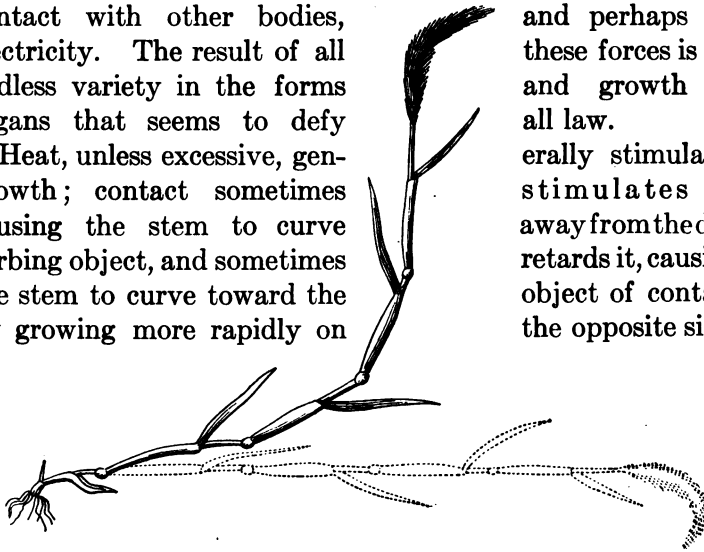


FIG. 70. — A piece of a haulm of millet that has been laid horizontally, righting itself through the combined influence of contact and negative geotropism.

as in the stems of twining vines. Light stimulates nutrition, but generally retards growth. The movements of plants toward the light are effected in this way; growth being checked on that side, the plant bends toward the light.

Practical Questions

1. Why do stems of corn, wheat, rye, etc., straighten themselves after being prostrated by the wind? (51, 54.)
2. Do plants grow more rapidly in the daytime, or at night? (54.)
3. Reconcile this with the fact that green plants will die if deprived of light.

4. Which grows more rapidly, a young shoot or an old one? (31, 50.)
5. Which, as a general thing, are the more rapid growers, annuals or perennials? Herbaceous or woody-stemmed plants?
6. Name some of the most rapid growers you know.
7. Of what advantage is this habit to them?
8. Why do roots form only on the under side of subterraneous stems? (51.)
9. Why do new twigs develop most freely on the upper side of horizontal branches? (51.)

Field Work

(1) Notice the various seedlings met with in your walks and see how many you can recognize by their resemblance to the mature plants. Account for any differences you may observe between seedlings and older plants of the same species. Observe the cotyledons as they come up and their manner of getting out of the ground, and notice the ways in which this is influenced by moisture, light, and the nature of the soil. Where the cotyledons do not appear, dig into the ground and find out the reason. Notice which method of emergence occurs in each case, the arched, or straight, and account for it. Observe particularly the behavior of seedlings in hard, sunbaked soil. If you see any of them lifting cakes of earth, compare the size and weight of the cake with that of the seed; if there is any disparity, what does this imply? What is the force called which the plant exercises in lifting the weight? (51.)

(2) Notice if there are any seeds germinating successfully on top of the ground, and find out by what means their roots get into the soil. Observe what effect sun and shade, moisture and drought, and the nature of the soil have on the process. Find out whether roots exercise force in penetrating the soil; what kinds they penetrate most readily, and what kinds, if any, they fail to penetrate at all. Notice whether seedlings with taproots, like the turnip and castor bean, or those with fibrous roots, like corn and wheat, are more successful in working their way downward.

(3) Look for tree seedlings. Explain why seedlings of fruit trees are so much more widely distributed in cultivated districts, and so much easier to find than those of forest trees. Where do the latter occur, as a general thing? Account for the fact that seedling trees are so much more rare than germinating herbs, and why trees like the oak and chestnut and black walnut propagate so much more slowly, in a state of nature, than the pine, cedar, ash, and maple.

(4) Observe the direction of growth in plants on the sides of gullies and ravines, and tell how it is influenced by geotropism. Notice whether there are other influences at work; for instance, light, or in the case of roots, the attraction of moisture.

CHAPTER III. THE ROOT

I. OSMOSIS AND THE ACTION OF THE CELL

MATERIAL. — For experiments in osmosis provide fresh and boiled slices of red beet, a fresh egg, a piece of ox bladder or some parchment paper; glass tubing, thread, twine, elastic bands, salt and sugar solutions. A common medicine dropper with the small end cut off will answer instead of tubing for making an artificial cell; or an eggshell may be used, by blowing out the contents through a puncture in the small end, and carefully chipping away a portion of the shell at the big end, leaving the lining membrane intact. The different liquids can be put into the shell and the exposed membrane placed in contact with the liquid in the glass, by fitting over the latter a piece of cardboard with a hole in the center large enough for the exposed surface to protrude sufficiently to touch the water.

55. Object of the experiments. — In order to understand clearly the action of roots in absorbing moisture from the soil, it will be necessary to learn something about the movement of liquids through the cells, upon which the physiological processes of the plant depend. For this purpose make an artificial cell by tying a piece of ox bladder or parchment paper tightly over one end of a small glass tube, as shown in Fig. 71.

EXPERIMENT 39. HOW DOES ABSORPTION TAKE PLACE IN THE CELL? — (a) Put some salt water in a wineglass, partly fill the tube of the artificial cell with fresh water, and mark on the outside of both vessels the height at which the contained liquid stands. Set the tube in the glass of salt water and wait for results, having first tested carefully to make sure that there are no leaks in the membrane. After half an hour, notice whether there is any increase of water in the glass, as indicated by the mark. If so, where did it come from? Is there any loss



FIG. 71.—Artificial cell.

of water in the tube? What has become of it? How did it get out? Taste it to see if any of the salt water has got in. Which is the heavier, salt water, or fresh? (If you do not know, weigh an equal quantity of each.) In which direction did the principal flow take place; from the heavier to the lighter, or from the lighter to the heavier liquid?

(b) Put a sugar or salt solution in the tube, and clear, fresh water in the glass, marking the height in each as before. Does the liquid rise or fall in the tube? Does any of it escape into the water of the glass, and if so, is it more or less than before? Which now contains the denser fluid, the tube or the glass? What principle governs the course of the liquid? Try the same experiment with (c), the same liquid in both vessels, and notice whether there is a greater flow in one direction than the other, as indicated by a comparison with the marks on the outside. (d) Put in the tube some of the white of a raw egg, insert in a glass of pure water, and note the effect. (e) Reverse, with water in the tube and white of egg in the glass. Does the water rise in the tube as before? Test the contents for proteins; has any of the albumin passed through the membrane into the tube?

EXPERIMENT 40. TO TEST THE BEHAVIOR OF LIVING AND DEAD CELLS. — Slice a fresh piece of red beet into a vessel of water and of a boiled one into another vessel of the same liquid at the same temperature. What difference do you notice? Can you think of any reason why the boiled one gives up its juices and the other one does not?

56. Osmosis. — The passage of liquids through membranes is known as *osmosis*. Our experiments have shown that the principles governing the osmotic movement are: (1) the flow of the thinner and lighter liquid toward the denser and heavier takes place more rapidly than in the opposite direction; (2) the rapidity of the flow depends on the difference in density; (3) solutions of crystallized substances, like sugar and salt, osmose readily; (4) albuminous substances, such as the white of an egg, osmose so slowly that the cell wall may be regarded as practically impermeable to them.

57. Osmosis a form of diffusion. — Osmosis is related to diffusion as a part to the whole. In other words, it is a name given to the process when it takes place through a membrane, whether solid, as the outer wall of the cell, or fluid, as the inner wall of living protoplasm. Diffusion may

take place without osmosis, — for example, when we sweeten our tea or coffee by allowing sugar to diffuse through it. It may also take place through the cell wall in connection with the osmotic current; or substances may diffuse into or out of the cell independently of osmosis. For this reason it is not safe to rely on the evidence of differently colored or differently tasting liquids in making experiments, unless we are sure of the osmotic properties of the solution, as the contained substances *may* diffuse through the membranes even though no interchange of liquids is going on at the time.

58. Absorption in living and dead cells. — There is one great difference between the action of the artificial cell used in the foregoing experiments and that of the cells of which a living body is built up. The former contains no protoplasm, and the osmosis is a purely mechanical process depending on the nature of the liquids, or possibly on some physical property of the membrane. Any substance to which the membrane is permeable can pass through. In the living cell the protoplasm exercises a power of absorption independent of the cell wall, sometimes rejecting substances admitted by the latter, sometimes retaining others to which it is permeable, as shown in Exp. 40. In the boiled beet the protoplasm had been killed and the red coloring matter passed through it unhindered, while in the living one it was held back by the protoplasmic lining, which is thus seen to control the absorptive properties of the cell.

59. Plasmolysis. — Cells can be killed or injured in other ways than by heat; for example, by cold, by poisons, by starvation, and by overfeeding through the use of too much fertilizer or too rich a one. In this last case, the soil water becomes impregnated with soluble matter from the manure, which may render it denser than the sap in the roots. When this happens, it will cause the osmotic flow to set outward and thus deplete the cell of its contents; whence we have the paradox that a cell, or even a whole plant, may be starved

by overfeeding. This action of osmosis in withdrawing the contents from a cell is termed *plasmolysis*, and you can easily understand how very important a knowledge of the principles governing it is to the farmer in determining the application of fertilizers to his crops.

Dead cells, although powerless to carry on the life processes of a plant, have nevertheless important uses in serving the purposes of mechanical support and also to some extent in assisting in the work of absorption, though their function here is a purely mechanical one.

60. Selective absorption. — Different plants through their roots absorb different substances from the soil water, or



FIG. 72. — Root absorbing mineral food from rock. The large sycamore, whose base is partly concealed by the trumpet creeper on the left of the picture, is growing in very hard, stony soil, and one of its main roots has molded itself so completely to the ledge of rock protruding on the right, that when a portion of it was torn away, as shown where the light streak ends at *a*, the impress of its fibers was so strongly marked on the rock as to give the latter the appearance of a petrified root.

the same substance in varying degrees. Hence, one kind of crop will exhaust the soil of certain minerals while leaving other kinds intact, or very little diminished; and *vice versa*, another kind will take up abundantly what its predecessor has rejected. In this sense, plants are said to exercise a selective power in the absorption of nutrients. The expres-

sion must not be understood, however, as implying any kind of volitional discrimination. It is merely a short and convenient way of saying that the cells of different plants possess different degrees of permeability to certain substances, some being more permeable to one thing, some to another. But beyond this rejection of untransmissible substances there is no

active power of discrimination, any substance that can pass through the cell wall and its protoplasmic lining being taken in, whether useful, unnecessary, or even harmful. The last two may be got rid of by excretion, as the superfluous water taken in with dissolved minerals is exhaled from the leaves; or if incapable of passing out by osmosis, rendered harmless and retained in the form of the curious "crystalloids" found in various parts of plants. But while the kind of selection exercised by vegetable cells implies no power of choice, as a matter of fact those substances most used by the plant in carrying on its life processes are absorbed in much greater quantities than others, being transferred to parts where growth or other changes in the plant tissues are going on, and there used up in the work of nutrition, or excreted in part as waste products. In either case their passage from cell to cell will give rise to a continuous osmotic current in that direction, and the absorption of new matter will go on in proportion to the amounts used up.

61. Definition. — Tissue is a word used to denote any animal or vegetable substance having a uniform structure organized to perform a particular office or function. Thus,



FIG. 73. — Roots of elm and sycamore contending for possession of the soil on a rocky bluff on the Potomac.

for instance, we have bony tissue and muscular tissue in animals; that is, tissue made of bone substance and muscle substance and doing the work of bone and muscle respectively. Likewise in plants, we have strengthening tissue made up of hard, thick-walled cells, serving mainly for purposes of mechanical support, and vascular tissue, made up of conducting vessels for conveying sap — and so on, for every separate function.

Practical Questions

1. Why do raspberries and strawberries have a flabby, wilted look if sugar has been put on them too long before they are served? (7, 56.)
2. Where has the juice gone? What caused it to go out of the berries? (56, 59.)
3. Is a knowledge of the principles governing osmosis of any practical use to the housekeeper?
4. Why cannot roots absorb water as freely in winter as in summer? (Suggestion: which is the heavier, cold or warm water?)
5. Why does fertilizing too heavily sometimes injure a crop? (59.)
6. Do you see any apparent contradiction between the action of plasmolysis and the selective power of protoplasm? Can you reconcile it?
7. If a piece of beet that has been frozen is placed in water it will behave just as the slice of boiled beet did in Exp. 40; explain. (58, 59.)

II. MINERAL NUTRIMENTS ABSORBED BY PLANTS

MATERIAL. — A dozen or two each of different kinds of seeds and grains. A small portion from a growing shoot of a woody and a herbaceous land plant, and of some kind of succulent water or marsh plant, such as arrow grass (*Sagittaria*), water plantain, etc.

APPLIANCES. — A pair of scales; a lamp, stove, or other means of burning away the perishable parts of the specimens to be studied.

EXPERIMENT 41. — DO THE TISSUES OF PLANTS CONTAIN MINERAL MATTER? — Take about a dozen each of grains and seeds of different kinds, weigh each kind separately, and then dry them at a high temperature, but not high enough to scorch or burn them. After they have become perfectly dry, weigh them again. What proportion of the different seeds was water, as indicated by their loss of weight in drying?

Burn all the solid part that remains, and then weigh the ash. What proportion of each kind of seed was of incombustible material? What proportion of the solid material was destroyed by combustion?

EXPERIMENT 42. — DO THEY CONTAIN DIFFERENT KINDS AND QUANTITIES OF MINERALS? — Test in the same way the fresh, active parts of any kind of ordinary land plant (sunflower, hollyhock, pea vines, etc.), and of some kind of succulent water or marsh plant (*Sagittaria*, water lily, fern). Do you notice any difference in the amount of water given off and of solid matter left behind? In the character of the ashes left? Have you observed in general any difference between the ashes of different woods; as, for instance, hickory, pine, oak? Compare with the residue left in Exp. 21; would you judge that the residual substances are of the same composition?

62. Essential constituents. — The composition of the ash of any particular plant will depend upon two things: the absorbent capacity of the plant itself and the nature of the substances contained in the soil in which it grows. But chemical analysis has shown that however the ashes may vary, they always contain some proportion of the following substances: potassium (potash), calcium (lime), magnesium, phosphorus, and (in green plants) iron. These elements occur in all plants, and if any one of them is absent, growth becomes abnormal if not impossible.

The part of the dried substances that was burned away after expelling the water consists, in all plants, mainly of carbon, hydrogen, oxygen, nitrogen, and sulphur, in varying proportions. These five rank first in importance among the essential elements of vegetable life, and without them the plant cell itself, the physiological unit of vegetable structure, could not exist. They compose the greater part of the substance of every plant, carbon alone usually forming about one half the dry weight. Other substances may be present in varying proportions, but the two groups named above are found in all plants without excep-



FIG. 74. — Water cultures of buckwheat, showing effect of the lack of the different food elements: 1, with all the elements; 2, without potassium; 3, with soda instead of potash; 4, without calcium; 5, without nitrates or ammonia salts.

tion, and so we may conclude that (with the possible addition of chlorine) they form the indispensable elements of plant food. Carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus compose the structure of which the plant is built. The other four ingredients do not enter into the substance as component parts, but aid in the chemical processes by which the life functions of the plant are carried on, and are none the less essential elements of its food. Figure 74 shows the difference between a plant grown in a solution where all the food elements are present, and others in which some of them are lacking.

63. How plants obtain their food material. — Plants obtain their supply of the various mineral salts from solu-



FIG. 75. — Roots of soy bean bearing tubercle-forming bacteria.

tions in the soil water which they absorb through their roots. With a few doubtful exceptions, they cannot assimilate their food unless it is in a liquid or gaseous form. Of the gases, carbon dioxide, oxygen, and hydrogen can be freely absorbed from the air, or from water with various substances in solution, but most plants are so con-

stituted that they cannot absorb free nitrogen from the air; they can take it only in the form of compounds from nitrates dissolved in the soil, and hence the importance of ammonia and other nitrogenous compounds in artificial fertilizers. Some of the pea family, however, bear on their roots little tubers formed by minute organisms called bacteria, which have the power of extracting nitrogen directly from the free air mingled with the soil; and hence the soil in which these tuber-bearing legumes decay is enriched with nitrogen in a form ready for use.

Practical Questions

1. Could any normal plant grow in a soil from which nitrogen was lacking? Potash? Lime? Phosphorus? (62.)
2. Could it live in an atmosphere devoid of oxygen? Nitrogen? Carbon dioxide? (62.)
3. Why are cow peas or other legumes planted on worn-out soil to renew it? (63.)
4. Is the same kind of fertilizer equally good for all kinds of soil? For all kinds of plants? (60, 62.)
5. Why does too much watering interfere with the nourishment of plants? (Exps. 26, 27.)
6. Are ashes fit for fertilizers after being leached for lye? (62.)
7. Why will plants die, or make very slow growth, in pots, unless the soil is renewed occasionally? (60, 62.)

III. STRUCTURE OF THE ROOT

MATERIAL. — Taproot of a young woody plant not over one or two years old; apple and cherry shoots make good specimens. For showing root hairs, seedlings of radish, turnip, or oat are good, also roots of wandering Jew grown in water; for the rootcap, corn, sunflower, squash.

64. Gross anatomy of the root. — Cut a cross section of any woody taproot, about halfway between the tip and the ground level, examine it with a lens, and sketch. Label the dark outer covering, *epidermis*, the soft layer just within that, *cortex*, the hard, woody axis that you find in the center, *vascular cylinder*, and the fine silvery lines that radiate from the center to the cortex, *medullary rays* (in a very young root these will not appear). Cut a section through a root that has stood in coloring fluid for about three hours and note the parts colored by the fluid. What portion of the root, would you judge from this, acts as a conductor of the water absorbed from the ground?

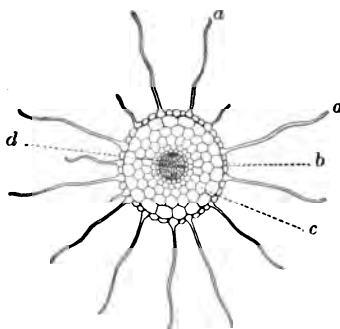


FIG. 76. — Cross section of a young taproot; *a*, *a*, root hairs; *b*, epidermis; *c*, cortical layer; *d*, fibrovascular cylinder. Note the absence of medullary rays during the first year of growth.

Make a longitudinal section passing through the central portion of the root and extending an inch or two into the lower part of the stem. Do you find any sharp line of division between them? Notice the hard, woody axis that runs through the center. This is the vascular cylinder and contains the conducting vessels, the cut ends of which were shown in cross section in Fig. 76.

65. Distinctions between root and stem. — Pull off a branch from the stem and one from the root; which comes off the more easily? Examine the points of attachment of the two and see why this is so.

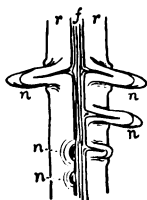


FIG. 77. — Vertical section of branching root, showing the branches, *n*, *n*, originating in the central axis, *f*, and passing through the cortex, *r*, *r*.

This mode of branching from the central axis instead of from the external layers, as in the stem, is one marked distinction between the structure of the two organs. In stems, moreover, branches occur normally above the points of leaf insertion at the nodes (46), while in the root they tend to arrange themselves in straight vertical rows. The shoots and cions that often originate

from them are not normal root branches, but outgrowths from irregular or *adventitious* buds, that may occur on any part of a plant. The root is not divided into nodes like the stem, and never bears leaves.

66. The active part of the root. — It is only the newest and most delicate parts of the root that produce hairs and are engaged in the active work of absorption, the older parts acting mainly as carriers. Hence, old roots lose much of their characteristic structure and take on more and more of



FIG. 78. — Root of a tree on the side of a gully, acting as stem.

the office of the stem, until there is practically no difference between them. On the sides of gullies, where the earth has been washed from around the trees, we often see the upper portion of the root covered with a thick bark and fulfilling every office of a true stem.

67. Minute structure of the root. — (a) Mount in water and place under the microscope a portion of the root of an oat or radish seedling containing a number of hairs. In studying the thin, transparent roots of very young seedlings a section will not be necessary. Observe whether the hairs originate from the epidermis or from the interior. Are they true roots, or mere outgrowths from the cells of the epidermis? Do they consist of a single cell or a number of cells each? Notice what very thin cell walls the hairs have; is there any advantage in this? The interior, transparent portion of the hair contains the sap, and the protoplasm forms a thin lining on the inner surface of the wall; why not the sap next the wall and the protoplasm in the interior? (58, 60.)

(b) Next examine a portion of the body of the root and try to make out the parts as shown in Fig. 79, and compare them with your observations in 64. The light line running through the middle is the *central cylinder*, up which the water passes, as was shown by the colored liquid in 64. Outside this is a darker portion (a, Fig. 79), corresponding to the cortex (rr, Fig. 77). Besides other uses, the cortex serves to prevent the loss of water as it passes up to the stem, and also, in fleshy roots like the carrot and turnip, for the storage of nourish-

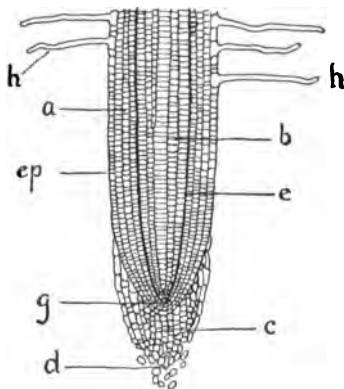


FIG. 79. — Longitudinal section through the tip of a young root, somewhat diagrammatic: h, h, root hairs; ep, epidermis; a, cortex; b, central cylinder; e, sheath of the cylinder (endodermis); g, growing point; c, root cap; d, dead and dying cells loosened from the extremity of the cap.

ment. Its innermost row of cells is thickened into the sheath, or *endodermis* (*e*), which serves as an additional protection to the conducting tissues. The extreme outer layer, from the cells of which the root hairs are developed, is, as already stated, the epidermis, and in the older and more exposed parts of perennial roots is displaced by the bark, which becomes indistinguishable from that of the stem. (66.)

(c) Look at the tip of the root for a loose structure (*c*) fitting over it like a thimble. This is the rootcap. Do you see any loose cells that seem to have broken away from it? These are old cells that have been pushed to the front by the formation of new growth back of them, and, being of no further use, are rubbed off by friction as the root bores its way through the soil. Draw a longitudinal section of the root as it appears under the microscope, labeling all the parts. If they cannot be made out distinctly in the specimen examined, use sections of young corn or bean roots, which are larger and show the parts more distinctly.

(d) Place under the microscope a thin cross section through the hairy portion of a primary root of a bean or pea

seedling, and try to make out the parts noted above and shown in cross section in Fig. 80. Make a sketch of what you see, labeling all the parts you can recognize. Show in your drawing the differences in the size and shape of the cells composing the different tissues. Notice in the central cylinder (Fig. 80) several groups of what look in the section like

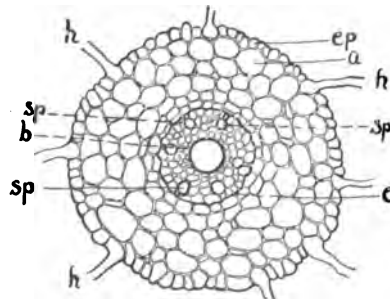


FIG. 80. — Cross section of a young root, magnified: *h*, hairs; *a*, cortex; *b*, central cylinder; *e*, sheath or endodermis; *ep*, epidermis; *sp*, cut ends of the ducts.

little round pits, or holes, *sp*. These are the cut ends of large-sized tubes or *ducts* that convey the water absorbed

by the roots to the stem. Each set of these tubes, together with a number of smaller ones belonging to the same group, constitutes a *fibrovascular bundle* — a very important element in the structure of all roots and stems, as these bundles make up the conducting system of the plant body.

IV. THE WORK OF ROOTS

MATERIAL. — Germinating seedlings of radish, bean, corn, etc.; a potted plant of calla, fuchsia, *tropæolum*, touch-me-not (*Impatiens*), or corn; a plant that has been growing for some time in a porous earthen jar.

APPLIANCES. — Glass tumblers; coloring fluid; wax; some coarse netting; dark wrapping paper, or a long cardboard box; a sheet of oiled paper; some half-inch glass tubing; a few inches of rubber tubing; an ounce of mercury; some blue litmus paper; a flower pot full of earth; a few handfuls of sand, clay, and vegetable mold; a pair of scales; a half dozen straight lamp chimneys, or long-necked bottles from which the bottoms have been removed as directed in Exp. 53.

EXPERIMENT 43. USE OF THE EPIDERMIS. — Cut away the lower end of a taproot; seal the cut surface with wax so as to make it perfectly water-tight, and insert it in red ink for at least half the remaining length, taking care that there is no break in the epidermis. Cut an inch or two from the tip of the lower piece, or if material is abundant, from another root of the same kind, and without sealing the cut surface, insert it in red ink, beside the other. At the end of three or four hours, examine longitudinal sections of both pieces. Has the liquid been absorbed equally by both? If not, in which has it been absorbed the more freely? What conclusion would you draw from this, as to the passage of liquids through the epidermis?

From this experiment we see that the epidermis, besides protecting the more delicate parts within from mechanical injury by hard substances contained in the soil, serves by its comparative imperviousness to prevent evaporation, or the escape of the sap by osmosis as it flows from the root hairs up to the stem and leaves.

EXPERIMENT 44. TO SHOW THAT ROOTS ABSORB MOISTURE. — Fill two pots with damp earth, put a healthy plant in one, and set them side by side in the shade. After a few days examine by digging into the soil with a fork and see in which pot it is drier. Where has the moisture gone? How did it get out?

EXPERIMENT 45. TO SHOW THAT ROOTS SHUN THE LIGHT. — Cover the top of a glass of water with thin netting, and lay on it sprouting mustard or other convenient seed. Allow the roots to pass through the netting into the water, noting the position of root and stem. Envelop the sides of the glass in heavy wrapping paper, admitting a little ray of light through a slit in one side, and after a few days again observe the relative position of the two organs. How is each affected by the light?

EXPERIMENT 46. TO FIND OUT WHETHER ROOTS NEED AIR. — Remove a plant from a porous earthenware pot in which it has been growing for some time; the roots will be found spread out in contact with the walls of the pot instead of embedded in the soil at the center. Why is this?

EXPERIMENT 47. TO SHOW THAT ROOTS SEEK WATER. — Stretch some coarse netting covered with moist batting over the top of an empty tumbler. Lay on it some seedlings, as in Exp. 45, allowing the roots to pass through the meshes of the netting. Keep the batting moist, but take care not to let any of the water run into the vessel. Observe the position of the roots at intervals, for twelve to twenty-four hours, then fill the glass with water to within 10 millimeters (a half inch, nearly) or less of the netting, let the batting dry, and after eight or ten hours again observe the position of the roots. What would you infer from this experiment as to the affinity of roots for water?

EXPERIMENT 48. WHAT BECOMES OF THE WATER ABSORBED BY ROOTS. — Cover a calla lily, young cornstalk, sunflower, tropæolum, or other succulent herb with a cap of oiled paper to prevent evaporation from the leaves, set the pot containing it in a pan of tepid water, and keep the temperature unchanged. After a few hours look for water drops on the leaves. Where did this water come from? How did it get up into the leaves?

EXPERIMENT 49. TO SHOW THE FORCE OF ROOT PRESSURE. — Cut off the stem of the plant 6 or 8 centimeters (3 or 4 inches) from the base. Slip over the part remaining in the soil a bit of rubber tubing of about the same diameter as the stem, and tie tightly just below the cut. Pour in a little water to keep the stem moist, and slip in above, a short piece of tightly fitting glass tubing. Watch the tube for several days and note the rise of water in it. The same phenomenon may be observed in the "bleeding" of rapidly growing, absorbent young shoots, such as grape, sunflower, gourd, tobacco, etc., if cut off near the ground in spring when the earth is warm and moist. By means of an arrangement like that shown in Fig. 81, the force of the pressure exerted can be measured by the displacement of the mercury. This flow cannot be due to the giving off of moisture by the leaves, since they have been removed. Their action, when present, by causing a deficiency of moisture in certain places may

influence the direction and rapidity of the current, but does not furnish the motive power, which evidently comes, in part at least, from the roots, and is the expression of their absorbent activity.

EXPERIMENT 50. TO SHOW THAT ROOTS GIVE OFF ACIDS. — Lay a piece of blue litmus paper on a board or on a piece of glass slightly tilted at one end to secure drainage. Cover the surface with an inch of moist sand and plant in it a number of healthy seedlings. Acids have the property of changing blue litmus to red; hence, if you find any red stains on the paper where the roots have penetrated, what are you to conclude?

The kind of acid given off may differ according to the soil the roots are growing in and the solutions it contains. Carbon dioxide has a slight acid reaction and is exhaled in varying quantities by all roots.

EXPERIMENT 51. CAN THE ABSORBENT POWER OF ROOTS BE INTERFERED WITH? — Place the roots of a number of seedlings with well-developed hairs in a weak solution of saltpeter — 10 grams (about $\frac{1}{4}$ of an ounce) to a pint of water, and others in a stronger solution — say 30 grams, or 1 ounce, to a pint. Try the same experiment with weak and strong solutions of any conveniently obtainable liquid fertilizer. After 45 minutes or an hour examine the roots under a lens and note the change that has taken place. What has gone out of them? What caused the loss of the contained sap?

EXPERIMENT 52. TO TEST THE WEIGHT OF SOILS. — Thoroughly dry and powder a pint each of sand and clay, measure accurately, and balance against each other in a pair of scales. Which weighs more, bulk for bulk, a "light" soil, or a "heavy" one?

EXPERIMENT 53. TO TEST THE CAPACITY OF SOILS FOR ABSORBING AND RETAINING MOISTURE. — Arrange, as shown in Fig. 82, a number of long-necked bottles from which the bottom has been removed. This can be done by making a small indentation with a file at the point desired and leading the break round the circumference with the end of a glowing wire or a red-hot poker. The crack will follow the heated object with sufficient

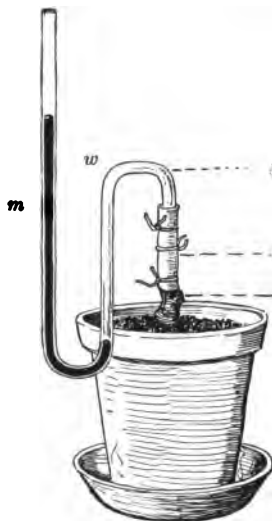


FIG. 81. — Arrangement for estimating the force of root pressure: *s*, stub of the cut stem; *g*, glass tubing joined by means of the rubber tubing, *t*, to the stem; *m*, mercury forced up the glass tube by water, *w*, pumped from the soil by the roots.

regularity to answer the purpose. Tie a piece of thin cloth over the mouth of each bottle and invert with the necks extending an inch or two into empty tumblers placed beneath. Fill all to the same height with soils of different kinds — sand, clay, gravel, loam, vegetable mold, etc. — and pour

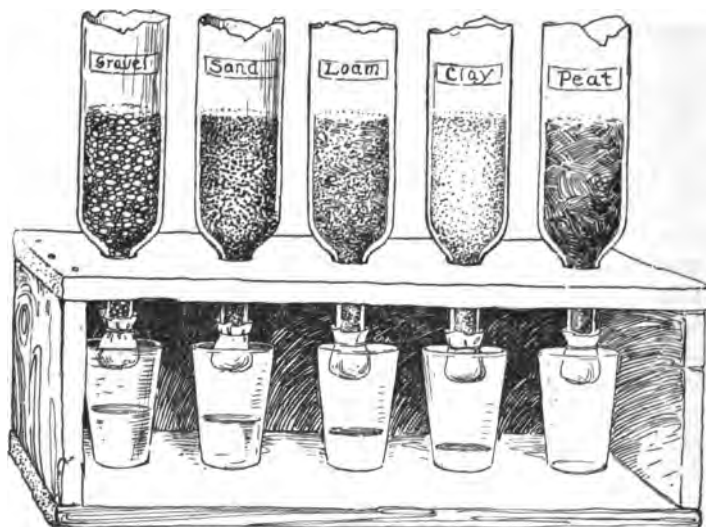


FIG. 82. — Apparatus for testing the capacity of soils to take in and retain moisture.

over each the same quantity of water from above. Watch the rate at which the liquid filters through into the tumblers. Which loses its moisture soonest? Which retains it longest?

Next leave the soils in the bottles dry, fill the tumblers up to the necks of the bottles, and watch the rate at which the water rises in the different ones. The power of soils to absorb moisture is called *capillarity*. Which of your samples shows the highest capillarity? Which the lowest? Do you observe any relation between the capillarity of a soil and its power of retention?

68. Roots as holdfasts. — One use of ordinary roots is to serve as props and stays for anchoring plants to the soil. Tall herbs and shrubs, and vegetation generally that is exposed to much stress of weather, are apt to have large, strong roots. Even plants of the same species will develop systems of very different strength according as they grow in sheltered or exposed places.

69. Root pull. — Roots are not mere passive holdfasts, but exert an active downward pull upon the stem. Notice the rooting end of a strawberry or raspberry shoot and observe how the stem appears to be drawn into the ground at the rooting point. In the leaf rosettes of herbs growing flat on the ground or in the crevices of walls and pavements, the strong depression observable at the center is due to root pull. (Fig. 84.)



FIG. 83. — Dandelion : *a*, common form, grown in plains region at low altitude ; *b*, alpine form.



FIG. 84. — Raspberry stolon showing root pull.

70. Storage of food. — Another office of roots is to store up food for the use of the plant. This is done chiefly in the tissues of fleshy roots and tubers, and gives to them their great economic value. Next to grains and cereals, roots probably furnish a larger portion of food to the human race than any other crop. In addition to this they are also the source of valuable drugs, condiments, and dyes.

71. Absorption and conveyance of sap. — But the most important function of roots is that of absorption. By their action the soil water and the minerals contained in it are drawn up into the plant body and made available for conversion by the leaves into organic foods, as will be explained in another chapter. From the nature of their function, most roots have naturally a

strong affinity for water, and its presence or absence has a marked influence on their direction of growth, being often sufficient to overcome that of geotropism (Exp. 47). There are many trees and shrubs, notably willow, sweet bay, red birch, and the like, that grow best on the banks of streams and ponds, where their roots can have direct access to water. Excess of moisture, however, is injurious to most land plants by preventing the roots from getting sufficient air for respiration.

72. The conditions of absorption. — The sap in the root cells is normally denser than the water in the soil, so there is a continuous flow from the latter to the former. But if, for any reason, the density of the liquids should be reversed, the flow would set in the opposite direction, and if continued long enough, the strength of the plant would be literally "sapped" by the exhaustion of its tissues, so that it would die. What is this process of cell exhaustion called?

73. The use of acid secretions to the root. — It was shown in Exp. 50 that roots give off carbon dioxide, which

has a slight acid reaction, and possibly other acids. These chemicals are active agents in dissolving the various mineral matters contained in the soil, and as these last can be absorbed only in a liquid or a gaseous state (63), the advantage to the root as an absorbent organ, of being able to secrete such active solvents, is obvious.

74. Relation of roots to the soil. — In order to perform their work of ab-



FIG. 85. — A natural root etching, found on a piece of slate.

sorption, roots must have access to a suitable soil. To produce the best results a soil must contain (1) all the essential mineral constituents (62); (2) moisture for dissolving these materials; and (3) air enough to supply the oxygen which is necessary to the life processes of all green plants.

75. Composition of soils. — Sand, clay, and humus, or vegetable mold, with the various substances dissolved in them, constitute the basis of cultivated soils. A mixture of sand, clay, and humus is called loam. When the proportion of humus is very large and well decomposed, the mixture is called *muck*. Pure sand contains but little nourishing matter and is too porous to retain water well. Pure clay is too compact to be easily permeable to either air or water. Most soils are composed of a mixture of the two with vegetable mold in varying proportions, giving a sandy loam, or a clay loam, as the case may be.

76. Tillage. — The advantages of tillage are: (a) that by breaking up the hard lumps it renders the soil more permeable to air and water and more easily penetrable by the roots in their search for food; (b) the covering of loose, friable earth left by the plow and the harrow acts as a mulch, and by shading the soil below, prevents too rapid a loss of water by evaporation. Where the essential food ingredients are present, good tillage counts for more in making a crop than the original quality of the soil.

77. Light and heavy soils. — These terms are used by farmers not in relation to the weight of soils, but in reference to the ease or difficulty with which they are worked. Light soils contain a preponderance of sand; heavy ones, of clay.

Practical Questions

1. Will plants grow better in an earthen pot or a wooden box than in a vessel of glass or metal? Why? (Exp. 46.)
2. Which absorb more from the soil, plants with light roots and abundant foliage, or those with heavy roots and scant foliage? (Suggestion: roots absorb from the soil; leaves, mainly from the air.)

3. Why are willows so generally selected for planting along the borders of streams in order to protect the banks from washing? (71.)
4. Why are the conducting tissues of roots at the center instead of near the surface as in stems? (67, b.)
5. Why does corn never grow well in swampy ground? (74; Exp. 46.)
6. Why are fleshy roots so much larger in cultivated plants than in wild ones of the same species? (74, 76.)
7. When the use of a particular kind of fertilizer causes the leaves of the plants to which it has been applied to turn brown, so that the farmer says they have been "burned" by it, to what cause is the trouble due? (59, 72.)
8. Why do farmers speak of turnips and other root crops as "heavy feeders"? (70, 71.)
9. Which is more exhausting to the soil, a crop of beets, or one of oats? Onions, or green peas? (See 2, suggestion.)
10. Why will inserting the end of a wilted twig in warm water sometimes cause it to revive? (Exps. 48, 49.)

V. DIFFERENT FORMS OF ROOTS

MATERIAL. — Examples of taproots: bean, pea, cotton, maple seedlings, or any kind of very young woody root. Fibrous: any kind of grass or grain. Fleshy: parsnip, turnip, carrot, dahlia, sweet potato. Water: duckweed, pondweed, or a cutting of wandering Jew grown in water. Parasitic: mistletoe, dodder, beech drops. Aërial and adventitious: the aërial roots of old scuppernong vines, climbing roots of ivy and trumpet vine, prop roots from the lower nodes of cornstalks and sugar cane.

78. Basis of distinction. — Roots vary in form and external structure according to their origin, function, and surroundings. In reference to the first, they are classed as primary or secondary; in regard to the second, as dry or fleshy; while as to surroundings, they may be adapted to either the soil, water, air, or the parasitic habit. Soil roots are the normal form. According to their mode of growth they are either fibrous or axial.

79. Taproots. — These are the common form of the axial type. Compare the root of any young hardwood cion a year or two old with one of a mature stalk of corn or other grain, and with the roots of seedlings of the same species. Notice the difference in their mode of growth. In



PLATE 3. — Aërial roots of a Mexican "strangling" fig, enveloping the trunk of a palm (*From "Rep't. Mo. Bot. Garden"*).

the first kind a single stout prolongation called a taproot proceeds from the lower end of the hypocotyl and continues the axis of growth straight downward, unless turned aside by some external influence. A taproot may be either simple,



FIG. 86. — Branched taproot of maple.

as in the turnip, radish, and dandelion, or branched, as in most shrubs and trees. In the latter case the main axis is called the primary root, and the branches are secondary ones.

80. Fibrous and fascicled roots. —

Where the main axis fails to develop, as in the corn and grasses generally, a number of independent branches take its place, forming what are known as fibrous roots. Both fibrous and taproots may be either hard or fleshy.

The turnip and carrot are examples of fleshy taproots, the dahlia and rhubarb of fascicled roots. The function of both is the storage of nourishment. The sweet potato is an example of a tuberous root.

81. Practical importance of this distinction. — The difference between axial and fibrous roots has important bearings in agriculture. The first kind, which are characteristic of most dicotyls, strike deep and draw their nourishment from the lower strata of the soil, while the fibrous and fascicled, or radial kinds, as we may call them for want of a better name, spread out near the surface and are more dependent on external conditions.

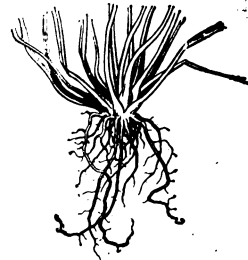


FIG. 87. — Fibrous root.

82. Roots that grow above ground. — The kinds of roots that have just been considered are all subterranean, and bring the plant into relation with the earth, whether for the purpose of absorbing nourishment, or of mechanical support, or, as in the majority of cases, for both. Many plants,

however, do not get their mineral nutrients directly from the soil, and these give rise to various forms suited to other conditions of alimentation.

83. Adventitious roots. — This name applies to any kinds of roots that occur on stems, or in other unusual positions. They may be considered as intermediate between the two classes named in 81; for while their starting point is above ground, they generally end by fixing themselves in the soil, where they often function as normal roots. Familiar examples are the roots that put out from the lower nodes of corn and sugar cane stalks, and serve both to supply additional moisture and to anchor the plant more firmly to the soil. Most plants will develop adventitious roots if covered with earth, or even if merely kept in contact with the ground. The gardener takes advantage of this capacity when he propagates by cuttings and layers.

84. Water roots. — These are generally white and thread-like and more tender and succulent than ordinary soil roots, because they have less work to do. Floating and immersed plants, such as bladderwort and hornwort (*Ceratophyllum*) have no need of absorbent roots, since the greater part of their surface is in contact with water and can absorb directly what is needed.

Land plants will often develop water roots and thrive for a time if the liquid holds in solution a sufficient quantity of air and mineral nutrients. Place a cutting of wandering Jew in a glass of clear water, and in from four to six days it will develop beautiful water roots in which both hairs and cap are clearly visible to the naked eye.

85. Haustoria, from a Latin word meaning to drain, or exhaust, is a name given to the roots of parasitic plants, or such as live by attaching themselves to some other living organism, from which they draw their nourishment ready made. Their roots are adapted to penetrating the substance of the *host*, as their victim is called, and absorbing the sap from it. Dodder and mistletoe are the best-known

examples of plant parasites, though the latter is only partially parasitic, as it merely takes up the sap from the host and manufactures its own food by means of its green leaves.

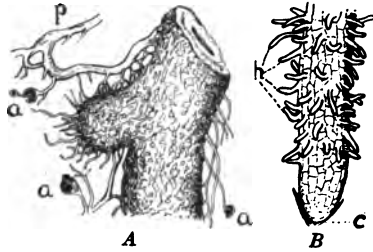


FIG. 88. — Beech root: A, grown in unsterilized wood humus: *p*, strands of fungal hyphae, associated at *a*, with humus; B, grown in wood humus freed from fungus by sterilization—it is not provided with fungal hyphae, and has root hairs, *h*. (A and B both several times magnified.)

part, at least, by association with certain saprophytic fungi, which enmesh their roots in a growth of threadlike fibers that take the place of root hairs and absorb organic food from the rich humus in which these plants grow. Such growths are called *mycorrhiza*, meaning “fungal roots.” Similar associations are formed by some of the higher plants also. The rootlets of the common beech and of certain of the pine family, for instance, are often enveloped in a network of fungus fibers, and in this case root hairs are developed very poorly, or not at all. Besides greatly increasing the absorbent surface by their ramification through the soil, the mycorrhizal threads may possibly benefit the plant in other ways also, as,

86. **Saprophytes.** — Akin to parasites are saprophytes, which live on dead and decaying vegetable matter. They are only partially parasitic and do not bear the haustoria of true parasites. Many of them, of which the Indian pipe (*Monotropa*) and coral root are familiar examples, obtain their nourishment in



FIG. 89. — An air plant (*Tillandsia*), growing on the underside of a bough.

for instance, by bringing about chemical changes that might aid in the work of nutrition.

87. Epiphytes, or air plants.—In the proper meaning of the word these are not parasitic, but use their host merely as a mechanical support to bring them into better light relations. The name, however, is loosely applied to all plants that find a lodgment on the trunks and branches of trees, whether parasites or true epiphytes that draw no nourishment from the host. Not infrequently the latter is killed by them through suffocation, overweighting, or the constriction of the stems by close clinging twiners.

88. Aërial roots are such as have no connection at all with the soil or with any host plant, except as they may lodge upon the trunks and branches of trees for a support. In other than purely epiphytic plants, which get all their nour-

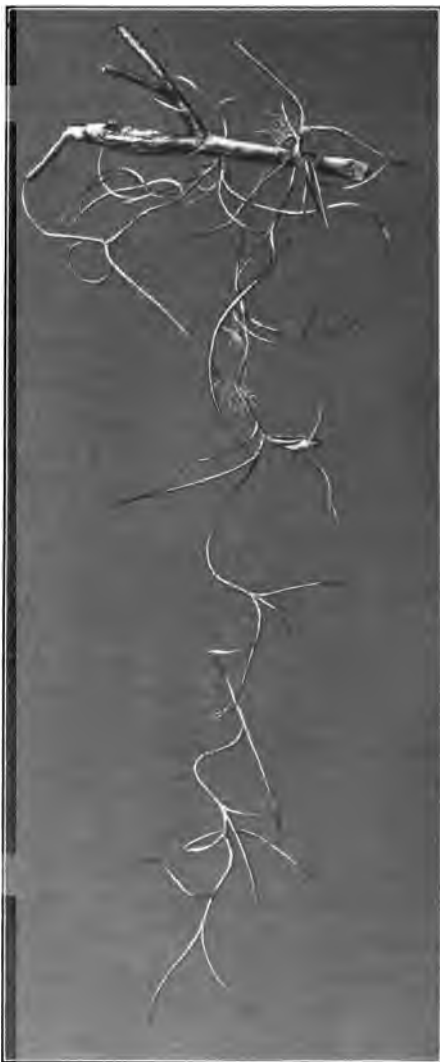


FIG. 90.—A single strand of *Tillandsia usneoides*, a rootless epiphyte belonging to the pineapple family; better known as the "Spanish moss" that drapes the boughs of trees so conspicuously in the warm parts of America. Two-thirds natural size. (Photographed by C. F. O'Keefe.)

ishment from the air, they are generally subsidiary to soil roots, like the long dangling cords that hang from some species of old grapevines; or they subserve other purposes altogether than absorbing nourishment, as the climbing roots of the trumpet vine and poison ivy. A very remarkable development of aërial roots takes place in the "strangling fig" of Mexico and Florida, which begins life as a small epiphyte, from seeds dropped by birds on the boughs or trunks of trees. When it gets well started, the young plant sends down enormous aërial roots, which find their way to the ground, and in time so completely envelop the host that it is literally strangled to death (Plate 3, p. 73). When this support is removed, the sheathing roots take its place and

become to all intents and purposes the stem of the fig tree, which now leads an independent life.

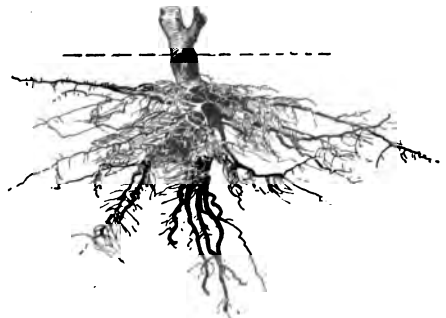


FIG. 91. — Root system of a tobacco plant.

89. The root system.

— The entire mass of roots belonging to a plant, with all its ramifications and subdivisions, composes a root

system. The extent of root expansion is in general about equal to that of the crown, thus bringing the new and active parts under the drip of the boughs where the moisture is most abundant. Some plants have root systems out of all seeming proportion to their size. A catalpa seedling six months old showed, by actual measurement, 250 feet of root growth, and it is estimated that the roots of a thrifty cornstalk, if laid end to end, would extend a mile. In the development of the root system, a great deal depends upon external conditions. In a poor, dry soil, the roots have to travel farther in search of a livelihood, and so a larger system has to be developed than in a more favorable location.

Practical Questions

1. Which is better to succeed a crop of turnips on the same land, hay or carrots? (81.)
2. Write out what you think would be a good rotation for four or five successive crops based on the forms of the roots.
3. Study the following rotations and give your opinion about them, on the same principle. Suggest any improvements that may occur to you, and give a reason for the change. Beets, barley, clover, wheat; cotton, oats, peas, corn; oats, melons, turnips; cotton, oats, corn and peas mixed, melons; cotton, hay, corn, peas.
4. Give three good reasons in favor of a rotation over a single-crop system. (24, 60, 62, 81.)
5. Which will require deeper tillage, a bed of carrots or one of strawberries? (81.)
6. Explain why some plants keep green and fresh when the surface of the soil is dry, while others wilt or die. (81, 89.)
7. Which will better withstand drought, a crop of alfalfa or one of Indian corn? Why? (81.)
8. Which will interfere less with the trees if planted in an orchard, beets or onions? (81.)
9. Ought a crop of hemp and tobacco to succeed each other on the same land? (81, 89.)
10. Why does a gardener manure a grass plot by scattering the fertilizer on the surface, while he digs around the roses and lilacs and deposits it under ground? (81.)
11. Do the adventitious roots of such climbers as ivy and trumpet vine draw any nourishment from the objects to which they cling? (83-88.)
12. How can you tell?
13. Do partial dependents of this kind injure trees by climbing upon them; and if so, how? (87, 88.)
14. What is the use of the aerial roots of the scuppernong grape? (88.)
15. Is the resurrection fern (*Polypodium incanum*), that grows on tree trunks in our Southern States, a parasite or an air plant? (87.)
16. On what plants in your neighborhood does mistletoe grow most abundantly? Dodder?
17. Is mistletoe injurious to the host? (85.)
18. Name some plants that are propagated mainly, or solely, by roots and cuttings.
19. Where do aerial roots get their nourishment? (88.)
20. Would they be of any use to a plant in a very cold or dry climate?
21. Where should manure be placed to benefit a tree or shrub with wide-spreading roots? (66, 89.)

22. Is it a wise practice to mulch a tree by raking up dead leaves and piling them around the base of the trunk, as is often done? Why, or why not? (66, 89.)

Field Work

(1) Examine the underground parts of hardy winter herbs in your neighborhood, also of any weeds or grasses that are particularly troublesome, and see if there is anything about the structure of these parts to account for their persistence. Note the difference between roots of the same species in low, moist places and in dry ones; between those of the same kind of plants in different soils; in sheltered and in exposed situations. Study the direction and position of the roots of trees and shrubs with reference to any stream or body of water in the neighborhood. (The elm, fig, mulberry, and willow are good subjects for such observations.) Notice also whether there is any relation between the underground parts and the leaf systems of plants in reference to drainage and transpiration.

(2) Observe the effect of root pull upon low herbs. Look along washes and gullies for roots doing the office of stems, and note any changes of structure consequent thereon. Study the relative length and strength of the root systems of different plants, with reference to their value as soil binders, or their hurtfulness in damaging the walls of cellars, wells, sewers, etc. Dig your trowel a few inches into the soil of any grove or copse you happen to visit, note the inextricable tangle of roots, and consider the fierce competition for living room in the vegetable world that it implies.

(3) Tests might be made of the different soils in the neighborhood of the schoolhouse by planting seeds of various kinds and noting the rate of germination; first, without fertilizers, then by adding the different elements in succession to see what is lacking. The field for study suggested by this subject is almost inexhaustible.

CHAPTER IV. THE STEM

I. FORMS AND GROWTH OF STEMS

MATERIAL. — Vigorous young hop or bean seedlings grown in pots; a fresh dandelion stalk; a stem of pea, squash, cucumber, grape, or passion flower vine, with tendrils.

APPLIANCES. — A bowl of fresh water; rods of different sizes and smoothness for testing the hold of climbers.

EXPERIMENT 54. TO SHOW THE MOVEMENTS OF TWINING STEMS. — Raise a young hop or bean seedling in the schoolroom and allow it to grow about two decimeters — 8 to 10 inches — in length before providing it with a support. Does the stem form any coils? Bring it in contact with a suitable upright support and watch for a day or two. What happens? Notice whether it starts to coil from right to left or from left to right and see if you can coax it to turn in the opposite direction. When it has reached the end of its stake, allow it to grow about five centimeters (two inches, approximately) beyond, and watch the revolution of the tip. Cut a hole through the center of a piece of cardboard about 14 centimeters (five to six inches) in diameter, slip it over the loose end of the stem, and fasten it to the stake in a horizontal position, with a pin. Note the position of the stem tip at regular intervals and mark on the cardboard; how long does it take to complete a revolution? Does it continue to coil, or to coil as readily, after leaving its stake as before? What would you infer from this as to the effect of contact in stimulating it to coil?

Find out by experiment if it can climb well by means of a glass or other smooth rod; by a fine wire; a broomstick; a large, smooth post. See whether it does better on a horizontal or an upright support.

EXPERIMENT 55. TO ILLUSTRATE THE COILING OF STEMS. — Run a gathering thread in one side of a narrow strip of muslin and notice how the ruffle thus drawn will curl into a spiral when allowed to dangle from the needle. Can you think of any cause that might act on a stem in the same way? Suppose, for instance, that one side should grow faster than the other; what would be the effect? (54.)

Split the stem of a fresh dandelion, or other herbaceous scape, longitudinally, and immerse it in a pan of fresh water for a few minutes. Notice how the two halves curve outward, or even coil up like the strip of muslin. This is due to the tension caused by the more rapid absorption of the

thinner walled cells of the internal tissues. These, when relieved of the resistance of the thicker walled outer tissues, swell on their free side, but are held back on the other by the non-absorbent outer parts, as one side of the muslin ruffle was held by the gathering thread.

EXPERIMENT 56. TO FIND OUT WHETHER THE DIRECTION OF STEM GROWTH IS INFLUENCED BY LIGHT. — Place two rapidly growing young pea, bean, sunflower, or squash plants, each with several well-developed leaves, in a room or box with a light exposure on one side only. After two or three days, notice the position of the stems in regard to the light. Does either one show a more decided inclination toward it than the other?

EXPERIMENT 57. IS THE LIGHT RELATION OF THE STEM INFLUENCED BY THE LEAVES? — Cut the leaves from one of the plants used in Exp. 56, covering the cut surfaces with vaseline to prevent "bleeding"; reverse the positions of both with regard to the light, and watch for two or three days. In which is the response to light the more rapid? What does this indicate as one object of the stem in seeking light? What is the best position of a stem, ordinarily, for getting its leaves into the light?

90. Classification. — Stems are classed according to (1) duration, as annuals, biennials, and perennials; (2) with

reference to hardness or softness of structure, as herbaceous and woody; (3) in regard to position and direction of growth, as erect, prostrate, climbing, inclined, declined, underground, etc.



FIG. 92. — Stems of red oak and hickory that have grafted themselves.

91. Annuals complete their life cycle in a single season and then die down as soon as they have perfected their seed. Many of our most troublesome weeds belong to this class and

might be exterminated by the simple expedient of mowing them down before their time of flowering.

92. Biennials, as the name implies, live for two years. Their energy during the first season is spent chiefly in laying by a store of nourishment, usually in the tissues of fleshy roots (70). By this means they get a good start in the second season and mature their seeds early. Many of our common garden vegetables, such as turnips, carrots, parsnips, and cabbage, belong to this class. Where is the nourishment stored in the cabbage?



FIG. 93. — A biennial plant, mullein, in winter condition with stem reduced to little more than a disk supporting a rosette of leaves. Notice how close they cling to the earth, and compare them with their fruiting condition a few months later as shown in Fig. 237.

93. Perennials are plants that live on indefinitely, like most of our forest trees and woody-stemmed shrubs.

Woody stems are usually perennial and may live for hundreds and even thousands of years, as those of the giant sequoias of California, and the famous chestnut of Mt. Etna.

94. Herbaceous stems are more or less succulent and die down after fruiting. They are usually annuals, though some kinds, like the garden geraniums and the common St.-John's-wort, show a tendency to become woody, especially at the base, and live on from year to year. Others, such as the hawkweed and dahlia, die down above ground in winter, but are enabled to keep their underground parts alive indefinitely, through the nourishment stored in them, and are thus perennial below ground and annual above. Woody-stemmed annuals, such as the cotton and castor oil plant, are not, properly speaking, herbs. In the tropical countries to which they belong they are perennial shrubs, or even small trees, but on being transplanted to colder regions

have been compelled to take on the annual habit as an adaptation to climate.

95. Direction and habit of growth. — As to manner of growth, there are many forms, from the upright boles of



FIG. 94. — Orange hawkweed with runners.



FIG. 95. — Prostrate stem of *Lycopodium* with assurgent branches.

the beech and pine to the trailing, prostrate, and creeping stems of which we have examples in the running periwinkle, the prostrate spurge and the creeping partridge berry (*Mitchella repens*), respectively. Trailing and prostrate stems are very apt to become creepers by the development of adventitious roots at their nodes wherever they come in contact with the soil. The rooting stems of dewberries, the runners and stolons of strawberries and currants, are familiar examples.

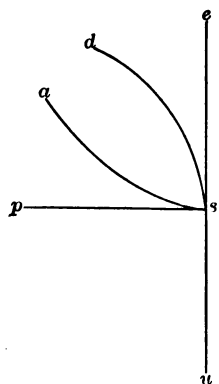


FIG. 96. — Diagram of stem growth: *ps*, surface of the ground; *e*, erect position; *d*, declined; *a*, assurgent; *p*, prostrate; *u*, vertical direction underground.

Between the extremes of prostrate and upright, stems may be inclined or bent in various degrees. As shown in Fig. 96, there are two modes of inclination: *assurgent*, *a*, from the prostrate, *p*, toward the upright, *e*; and *declined*, *d*, from the upright

toward the prostrate. Below the surface, *ps*, occur only underground stems. Is the prostrate habit an advantageous one for light exposure? Can you think of any compensating advantages a plant might derive from it; for example, in regard to warmth and moisture?

96. Climbing stems. — These are such as lift themselves from the ground and attain the advantages of the upright position by clinging to supports of various kinds — usually, in a state of nature, the stems and boughs of other plants. The means of climbing may be: (1) by merely leaning upon or propping themselves up by the aid of the supporting object — examples, the rose, wistaria, star jessamine (*Jasminum officinalis*); (2) by coiling their main axes spirally around the support — hop, bean, morning-glory; (3) by means of adventitious roots — poison ivy, common English ivy, trumpet vine (*Tecoma radicans*); (4) by organs specially developed for the purpose, called tendrils — gourd, cucumber, grape, passion flower.



FIG. 97. — Twining stems:
A, hop twining with the sun;
B, convolvulus twining against
the sun.

97. Tendrils. — The part assigned to do the work of climbing may be a secondary branch, a flower stem, a leafstalk, a leaf, a leaflet, or a group of leaflets (Fig. 98). Tendrils behave in general very much like twining stems, except that they are more sensitive and respond more quickly to any cause that may influence their movement. While young, their tips revolve just as do the tips of twining stems, until they meet with an object round which they can coil. When this happens, not only the part in contact with the object coils, but the free part between it and the main axis will usually respond by twisting itself into a helix (Fig. 99). As the distance between the base and tip of the tendril is shortened



FIG. 98.—Leaf of common pea, showing upper leaflets reduced to tendrils.

by coiling, the body of the plant is drawn upward proportionally. It will be observed that the helix is interrupted at one or more points, above and below which the coils turn in opposite directions. This is because the tendril is attached at both ends and cannot adjust itself to the opposite strains of torsion. Twist with your fingers a piece of tape so attached, and you will see that on one side of your hand it turns from right to left and on the other from left to right.

98. The cause of twining.—

Botanists are not fully agreed on this point. The explanation most generally accepted at present is that the twining of stems is due to the combined action of lateral and negative

geotropism (51). The first causes one side to grow more rapidly than the other,

thus forming a succession of coils, while the second, by stimulating the upward growth of the axis, stretches it into a spiral, and in this way draws it more tightly round the support. For this reason twining stems do best on an upright support.

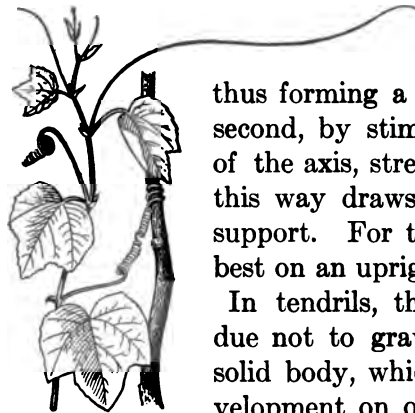


FIG. 99.—Stems of a passion flower transformed into tendrils. (After GRAY.)

In tendrils, the twining is thought to be due not to gravity, but to contact with a solid body, which, by inducing unequal development on opposite sides of the tendril, causes it to turn about an available object. The coiling of the free part of the twining organ is in response to the stimulus trans-

mitted from the part in contact — *stimulus*, in this sense, denoting the influence of any external agent that calls forth a responsive adjustment on the part of the plant.

99. The object of the various habits of stem growth. — To bring the growing parts of the plant into the best possible relations with light and air is one of the special functions of the stem, and the various habits of growth described in this section have been developed with reference to this function. In the case of prostrate and underground stems other factors may intervene; can you name some of the causes that might influence the position of the stem in such cases?



FIG. 100. — Showing the economy of labor and building material effected by the climbing habit. Notice how the grapevine coils like an anaconda around the tree boles, and overtops their tallest branches. Compare the diameter of the vine with that of the trees.

Practical Questions

1. Why is the normal direction of most stems upright? (Exp. 56.)
2. Name a dozen woody-stemmed plants; a dozen with herbaceous stems.
3. Name all the plants you can think of that have prostrate stems, or leaf rosettes that hug the earth, like mullein and dandelion. Which of these are wintergreen plants? Which are hot-weather growers?
4. Can you explain in what ways both hot-weather and cold-weather plants may be advantaged by the habit of clinging close to the earth? (94, 95.)
5. Is there any difference in the height of the stem of a dandelion flower and a dandelion ball?
6. Of what advantage is this to the plant? (Exp. 17.)
7. Name all the means you can think of by which a stem may climb, and give an example of each.

8. Why do we support peas with brush, and hops or beans with poles? (98; Exp. 54.)
9. Are the vines of gourds, watermelons, squashes, and pumpkins normally climbing or prostrate? How can you tell? (96, 97.)
10. Why does not the gardener provide them with poles or trellises to climb on?
11. Do twining plants grow equally well on horizontal and upright supports? (98; Exp. 54.)
12. If there is any difference, which do they seem to prefer?
13. Can you give any reasons for thinking that the climbing habit might lead to parasitism? (83, 85, 87.)
14. What method of climbing would be most favorable to the development of such a habit? (Suggestion: What mode of climbing brings the stem into closest contact with its support?)
15. Name some plants the stems of which are used as food.
16. Name some from which gums and medicines are obtained.
17. Explain how it can benefit a plant to have its leaves, or some of them, modified into tendrils. (99.)
18. In what way is the loss of the normal function of the leaves so modified, compensated for? (Exp. 57.)
19. Suppose the vine shown in Fig. 100 had to lift itself without the aid of a support; could it reach the same height and carry the same weight of foliage and flowers with the same expenditure of labor and building material?

II. MODIFICATIONS OF THE STEM

MATERIAL. — A shoot of asparagus; thorny branches of locust, plum, or haw; a cactus plant; bulbs of lily and hyacinth or onion; tubers of potato; rootstocks of iris, fern, or violet. If fresh specimens are not accessible, dried rootstocks of the sweet flag and Florentine iris may be obtained at the drug stores under the names of *calamus* and "*orris*" root.

100. How to recognize modified parts. — Stems, like roots, are often modified to serve other than their normal purpose, and in adapting themselves to these new functions they sometimes undergo such changes of form and structure that it would be impossible to recognize their true nature from appearances alone. The safest tests in such cases are: (1) by a comparison of the parts of the modified structure with those of known organs of the same kind; and (2) by observing its position in reference to other parts. For

instance, we know that the stem is the part of the plant which normally bears leaves and flowers, and if either of these, or if the small scales which often take the place of leaves, are found growing on any plant structure, we may usually take for granted that it is a stem. Then, again, as will be shown in the next chapter, buds and branches naturally appear only at the nodes, in or near the *axil*, or inner angle made by a leaf with the stem. Hence, if you see any growth springing from such a position, you may generally conclude it to be a stem.

101. Stems as foliage. — The connection between stem and leaf is so intimate that we need not be surprised to find a frequent interchange of function between them, the leaf, or some part of it, doing the work of the stem (Fig. 98), the stem more often taking upon itself the office of the leaf. A common example is the garden asparagus. Examine one of the young shoots sold in the market, and notice that it bears a number of small scales in place of leaves. On an older shoot that has gone to seed, the green, threadlike appendages, which are usually taken for foliage, will be found to spring each from the axil of one of these scales. What, therefore, are we to conclude that it is?



FIG. 101.—Stem-leaves (cladophylls) of a *ruscus*, bearing flowers.

In the butcher's-broom of Europe, the transformation has gone so far that the branches of the stem have assumed the flattened appearance of leaves (Fig. 101), but their real nature is evident both from their position in the axils of leaf scales, and from the fact that they bear flower clusters in the axil of a scale on their upper face. Another example of this sort of modification is seen in the pretty little *mysiphylum* of the greenhouses (wrongly called *smilax*), which

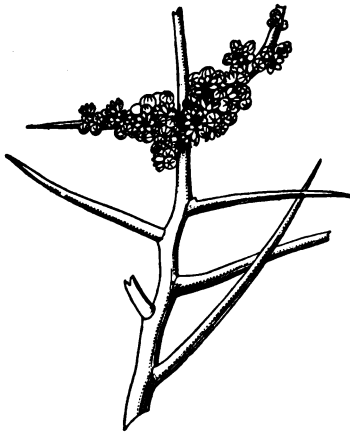


FIG. 102.—Thorn branches of *Holocantha Emoryi*, a plant growing in arid regions.

is so much used for decoration. The delicate green blades are merely altered stems, shortened and flattened to simulate leaves.

102. Weapons of defense.—

Conspicuous examples of these are the bristling thorns of the honey locust. Is their frequent branching any indication of their real nature? Does it *prove* anything, or must you look for other evidence? What further indications might you expect to find, if they are true branching stems? (100.) On old haw,

plum, crab, and pear trees, stems can be found in all stages of transition, from stubby, ill-developed branches, to well-defined thorns.

103. Storage of nourishment.— This is one of the most frequent causes of modification in both roots and stems. Of stems that grow above ground, the sugar cane probably comes first in economic importance on this account. In hot, arid regions, where the moisture drawn from the earth would, during prolonged drought, be too rapidly dissipated by an expanded surface of leaves, the whole plant, as in the case of the cactus, is sometimes compacted into a greatly thickened stem, which fills the triple office of leaf, stalk, and water reservoir.

104. The uses of underground stems.—

It is in these that the storage of nourishment most frequently takes place, and the modifications that stems undergo for this purpose are in some cases so great that their real



FIG. 103.—Melon cactus, showing greatly condensed stem for the storage and preservation of moisture.

nature becomes apparent only after a careful examination. But while the chief function of underground stems is the storage of nourishment, they serve other purposes also. In plants requiring a great deal of moisture, like the ferns, and in others growing in dry places and needing to husband moisture carefully, like the blackberry lily, underground stems may be useful in preventing the too rapid evaporation that would take place through aerial stems. Defense against frost, cold, heat, and other dangers, as well as quickness of propagation, are also attained or assisted by this means.



FIG. 104. — Rootstock of creeping panic grass.

105. Rootstocks and rhizomes.— From a prostrate stem like that shown in Fig. 95 to a creeping rootstock like the one in Fig. 104, the transition is so easy that we find no difficulty

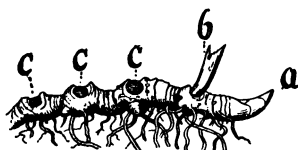


FIG. 105. — Rhizome of Solomon's seal: *a*, growing bud at the tip; *b*, remains of the past season's flower stem; *c, c, c*, scars of old stems. (After GRAY.)

in accounting for it. From the prostrate rootstock to the thickened storage rhizome (Fig. 105) of such plants as the iris, puccoon, bulrush, and Solomon's-seal, is a longer step, but the bud with its leaf scales at the growing tip, *a*, the remains of the flower stem at the node, *b*, and the roots from the under surface sufficiently indicate its nature. The peculiar scars from which the Solomon's seal takes its name are caused by the falling away each year of the flowering stem of the season after its work is done, leaving behind the node of the underground stem from which it originated. In this way the rhizome lives on indefinitely, growing and increasing at one end as fast as it dies at the other. Test a little of the substance of the rhizome with iodine. Of what does it consist? Of what use is it to the plant?

106. The tuber.— A still further thickening and shorten-

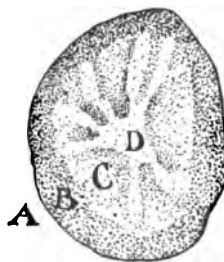
ing of the rhizome gives rise to the tuber, of which the potato and the Jerusalem artichoke are familiar examples. Can you give any evidence to show that the potato is a



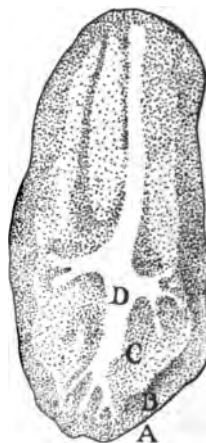
FIG. 106. — Potato tuber showing lenticels, A, A, or pores for air on the surface; S, leaf scale, or scar.

modified stem? Find the point of attachment of the tuber to its stem and stand it on this end, which is its natural base. Notice that the eye sits in the axil of the little scale that forms the eyelid. What does the scale represent? What is the eye? (100.) Do the scales occur in any regular

order — that is, opposite, or alternating with, each other, like the leaves on a stem? Look on the surface for a number of small, lens-shaped dots (A, A, Fig. 106) scattered irregularly over it. These are aërating pores called *lenticels*, and are found in most dicotyl stems. Does their presence help to throw light on the real nature of the tuber? If any sprouts occur on your specimen, where do they originate? Where do buds and sprouts originate on plants above ground? Make a sketch of the outside of a potato, showing the lenticels, eyes, and scales, or the scars left



107



108

FIGS. 107, 108. — Transverse and longitudinal sections of the potato: A, skin; B, cortical layer; C, outer pith layer; D, inner pith layer.

by the scales in case they have fallen away, as has probably happened, if your specimen is an old one.

Cut a small slice from the stem end of two potatoes, stand

them in coloring fluid for four or five hours, then divide into cross and vertical sections, as shown in Figs. 107, 108, and draw, labeling the parts that you can make out. Through which has the liquid ascended most rapidly? Test with iodine and find out in which part nourishment is most abundant. It is this abundant store of food that makes the potato such a valuable crop in cold countries like Norway and Iceland, where the seasons are too short to admit of the slow process of developing the plant from the seed.

Compare a common potato with a sweet potato. Are there any eyes or buds on the latter? Is there a scale below them? Do they occur in any regular order? Do you see any lenticels? The common potato and the sweet potato are both tubers; can you give some of the reasons why the one is regarded as a modified branch, and the other as a root? (100.) Compare their food contents; which contains most starch? Which most sugar? How can you judge about the sugar without a chemical test?



FIG. 109.—Scaly bud of oak, enlarged.



FIG. 110.—Scaly bulb of lily (GRAY).

107. The bulb is a form of underground stem reduced to a single bud. Get the scaly bulb of a lily, and sketch it from the outside and in cross and vertical section. Compare it with the scaly winter buds of the oak and hickory, or other common deciduous tree. Make an enlarged sketch of the latter on the same scale as the lily bulb, and the resemblance will at once become apparent. The scales of the bulb are, in fact, only thick, fleshy leaves closely packed around a short axis that has become dilated into a flat disk. From the center of the disk, which is the terminal node of this transformed stem, rises the flower stalk, or *scape*, as it is called, of the season. After blossoming, the scape perishes with its bulb, and their place is taken by new ones which are developed

from the axils of the scales, thus revealing their leaflike nature.

That bulbs are only modified buds is further shown by the bulblets that sometimes appear among the flowers of the onion, and in the leaf axils of certain lilies. They never develop into branches, but drop off and grow into new plants just as the subterranean bulbs do.



FIG. 111. — Leaf of an onion divided lengthwise, showing the base enlarged into the coat of a bulb.

The bulbs of the onion and hyacinth are still further modifications, in which the scales consist of the thickened bases of leafstalks that are dilated until each one completely envelops the growing parts within.

108. Morphology is the part of botany that treats of the origin, form, and uses of the different organs of plants, and of the modifications they undergo in adapting themselves to changes of condition or function. Organs or parts that have the same origin but have become adapted to different functions, like the flattened stems of the butcher's-broom or the bulb scales of the lily, are said to be *homologous*; those that are different in origin but adapted to the same function, as the sweet and common potatoes, are *analogous*. In other words, homologous organs are morphologically alike, but may be physiologically different; analogous organs are alike physiologically, but differ morphologically.

109. Economic value of stems. — We probably get a greater variety of economic products from the stem than from any other part of the plant. Consider the vast amount of food stored in underground stems like the potato; the resins, gums, and sugar found in the sap of plants like the sugar cane, the pine, and India-rubber trees; the medicines, dyes, and extracts obtained from the tissues; the valuable fibers, such as flax, jute, and hemp, furnished by the bast; the wood pulp for making paper; and the timber

for building and furnishing our houses that we get from the woody trunks of trees. When we think of all these things, it seems hardly possible to overestimate the importance of this part of the vegetable kingdom to man, or to exert ourselves too strenuously to regulate and prevent the destruction of these invaluable natural resources.

Practical Questions

1. Would you judge from the observations made in the foregoing section, that the work of an organ determines its form, or that the form determines its work? (99, 100, 108.)

2. Which is the more important, form or function?

3. Name some plants that are propagated by rootstocks; by runners or stolons; by rhizomes; by tubers; by bulbs.

4. What is the advantage of propagating in this way over planting the seed? (104, 106.)

5. Mention any other advantages that the various plants named may gain from the development of their underground parts. (104.)

6. What makes the nut grass so troublesome to farmers in some parts of the country?

7. Is its "nut" a root or a tuber? How can you tell? (106.)

8. Suggest some ways for destroying weeds that are propagated in this way.

9. Could you get rid of wild onions in a pasture by mowing them down? By digging them up? (107.)

10. Is it wise for farmers to neglect the appearance of such a weed in their neighborhood, even though it does not infest their own land?

11. Name any plants of your neighborhood, either wild or cultivated, that are valued for their rhizomes; for their tubers.

12. What part of the plants named below do we use for food or other purposes? Ginger, angelica, ginseng, cassava, arrowroot, garlic, onion, sweet flag, iris, sweet potato, Cuba yam, artichoke.

13. Why are the true roots of bulbous and rhizome-bearing plants generally so much smaller in proportion to the other parts than those of ordinary plants? (89, 104.)

14. If the Canada thistle grows in your vicinity, examine the roots and see if there is anything about them that will help to account for its hardiness and persistency.

15. If you live in the region of the horse nettle (*Solanum Carolinense*), explain how it is helped by its root system. (89.)

III. STEM STRUCTURE

A. MONOCOTYLS

MATERIAL. — Fresh cornstalks with several well-developed nodes, some of which should have stood in coloring fluid from 1 to 3 hours. If fresh specimens cannot be obtained from the fields, a number of seedlings may be grown in boxes of rich earth and cared for by the pupils either at home or in the schoolroom; they should be planted 4 or 5 weeks before needed. Asparagus and smilax sprouts may be used, or the stem of any large grass, or of wheat and other grains, but stalks of corn or sugar cane make the best subjects for study where they can be obtained.

APPLIANCES. — A compound microscope will be needed for detailed study. Prepared slides can be used, but it is better for students to make their own sections where practicable.

110. Gross anatomy of a monocotyl stem. — Obtain a fresh cornstalk, — preferably one that has begun to tassel, — and observe its external characters. How are the inter-

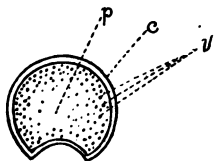


FIG. 112. — Cross section of a cornstalk (reduced): *v*, fibro-vascular bundles; *c*, cortex; *p*, pith.

nodes divided from one another? What is the use of the very firm, smooth epidermis? Notice a hollow, grooved channel running down one side between the *joints*, or nodes; does it occur in all of them? Is it on the same side or on the opposite sides of alternate internodes? Follow one of these grooves to the node from which it originates; what do you find there?

After studying the internal structure of the stalk, you will understand why this groove should occur on the side of an internode bearing a bud or fruit.

Cut a cross section midway between two nodes, and observe the composition of the interior; of what does the bulk of it appear to consist? Notice the arrangement of the little dots, like the ends of cut-off threads, that are scattered through the pith; where are they most abundant, toward the center or the circumference?

Make a vertical section through one of the nodes. Cut a thin slice of the pith, hold it up to the light, and examine

with a hand lens. Observe that it is composed of a number of oblong cells packed together like bricks in a wall. These are filled with protoplasm and cell sap, and constitute what is known to botanists as the *parenchyma* or fundamental tissue from which all the other tissues are derived. Apply the iodine test; in what parts does starch occur most abundantly?

Draw out one of the woody threads running through the pith. Break away a bit of the epidermis, and see how very closely they are packed on its inner surface. Trace the course of the veins in the bases of the leaves; find their point of union with the stem; with what part of it do they appear to be continuous? Has this anything to do with the greater abundance of fibers near the epidermis? Can you follow the fibers through the nodes, or do they become confused and intermixed with other threads there? (If a stalk of sugar cane can be obtained, the ring of scars left by the vascular bundles as they pass from the leaves into the stem will be seen beautifully marked just above the nodes.)

If there is an eye or bud at the node, see if any of the threads go into it. Can you account now for the depression that occurs in the internode above the eye?

Make drawings of both cross and vertical sections, showing the points brought out in your examination of the cornstalk.

III. The vascular system. — To find out the use of the threads that you have been tracing, examine a piece of a living stem that has stood in red ink for three to twenty-four hours. Notice the course the coloring fluid has taken; what would you infer from this as to the use of the woody fibers?

These threads constitute what is called the *vascular system* of the stem, because they are made up of *vessels* or *ducts*, along which the sap is conveyed from the roots to the leaves

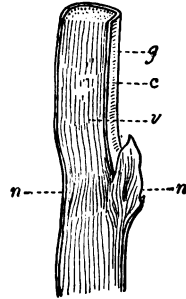


FIG. 113. — Vertical section of cornstalk (reduced): *g*, groove; *c*, cortex; *v*, fibrovascular bundles mingled with parenchyma; *b*, bud; *n*, node.

and back from the leaves to the parts where it is needed after it has contributed to the elaboration of food.

On account of this double line of communication which they have to maintain, the vascular threads, or *bundles*, as they are technically called, are double; one part composed of larger vessels, carrying water up, the other consisting of smaller ones, bringing back the food. Can you give a reason for their difference in size?

112. Woody monocotyls. — Examine sections of yucca, smilax, or of palmetto from the handle of a fan, and compare them with your sketches of the cornstalk. In which are the vascular fibers most abundant? Which is the toughest and strongest? Why? Trace the course of the leaf fibers from the point of insertion to the interior. How does it differ from that of the fibers in a cornstalk?



FIG. 114. — Longitudinal section through the stem of a palm, showing the curved course of the fibrovascular bundles (GRAY, after FALKENBERG).

113. Growth of monocotyl stems. — After tracing the course of the leaf veins at the nodes of the cornstalk, you will have no difficulty in identifying these veins as part of the vascular system. In jointed stems like those of the corn and sugar cane and other grasses, their intercalation between the vascular bundles of the stem takes place, as we have seen, at the nodes, forming the hard rings known as joints; but in other monocotyls the fibers entering the stem from the leaves usually tend first downward, toward the interior (Fig. 114), then bend outward, toward the surface, where they become entwined with others and form the tough, inseparable cortex that gives to palmetto and bamboo stems their great strength. Generally, monocotyl stems do not increase in diameter after a certain point, and as they can contain only a limited number of vascular fibers, they are incapable of supporting an extended system of leaves and branches. Hence



PLATE 4. — Forest of bamboo, showing the tall, straight, branchless habit of monocotyl stems.



plants of this class, with a few exceptions, like smilax and asparagus, are characterized by simple, columnar stems and a limited spread of leaves. Such plant forms are admirably adapted by their structure to the purposes of mechanical support. It is a well-known law of mechanics that a hollow cylinder is a great deal stronger than the same mass would be in solid form, as may easily be tested by the simple experiment of breaking in your fingers a cedar pencil and a joint of cane or a stem of smilax of the same weight. In stems that may be technically classed as solid in structure, like the corn and palmetto, the interior is so light compared with the hard epidermis that the result is practically a hollow cylinder.

114. Minute study of a monocotyl stem. — Place under the microscope a very thin transverse section of a cornstalk.

The little dots that looked like the cut ends of threads to the naked eye will now appear as

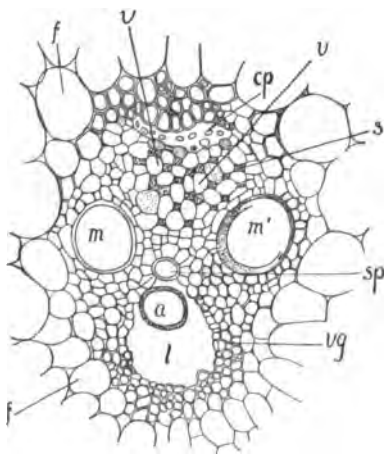


FIG. 115.—Transverse section through the fibrovascular bundle of a cornstalk: *a*, annular tracheid; *sp*, spiral tracheid; *m* and *m'*, ducts; *l*, air space; *v*, sieve tubes; *s*, companion cells; *vg*, strengthening fibers; *cp*, bast; *f*, *f*, parenchyma.

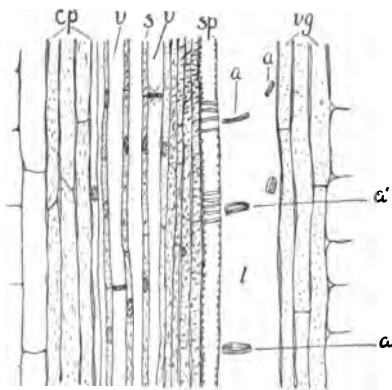


FIG. 116.—Vertical section of the same; *a* and *a'*, rings of a decomposed annular tracheid; *v*, sieve tubes; *s*, companion cells; *cp*, bast; *l*, air space; *vg*, strengthening tissue; *sp*, spiral duct.

the complex group of cells shown in Fig. 115. The same parts are shown longitudinally in Fig. 116. As seen in cross sec-

tion

tion, their arrangement suggests a grotesque resemblance to the face of an old woman wearing a pair of enormous spectacles and surrounded by a cap frill of netting with very wide meshes. These are parenchyma cells, *f, f*, Fig. 115, and constitute the greater portion of the living tissues.

The two large openings, *m, m'*, that represent the spectacles, are ducts for carrying water *up* the stem. They are called pitted ducts on account of the bordered pits which cover their outer surface. The two smaller openings between and slightly below the pitted ducts are also vessels for carrying liquids up the stem. The lower one, *a*, is called the annular tracheid because its tube is strengthened by rings on the inside. The upper, smaller one, *sp*, is known as the spiral tracheid, because its walls are reinforced by spiral thickenings. Can you think what is the use of these strengthening contrivances in the walls of conducting cells? (Suggestion: What is the use of the spiral wire on a garden hose?) The large, irregular opening below the ducts is an air space. What is its object? Why has it no surrounding wall?

Next look above the ducts for a group of rhomboidal or hexagonal cells, *v, v*, with smaller ones, *s*, between them. The larger of these are *sieve tubes*, the smaller ones, *companion cells*. The sieve tubes carry sap *down* the stem after it has been made into food by the leaves. They get their name from the sievelike openings between the connecting walls of the cells which form them — as if a row of pepper boxes with perforations at both top and bottom were placed end to end, so as to form a long tube divided into compartments by perforated walls. Can you give a reason why the cells of ducts that carry elaborated nutriment should have a more open line of communication than those carrying crude sap? [56 (2).] Which one of the organic food substances was shown by Exp. 39 to be unable, or nearly so, to pass through

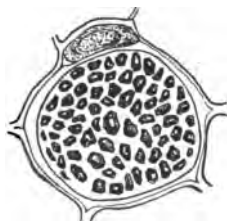


FIG. 117. — Horizontal view of the sieve tube of a gourd stem, showing perforations.

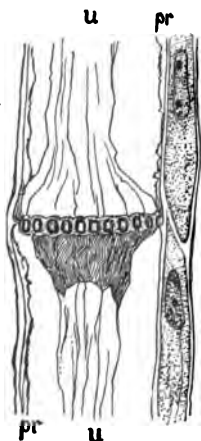


FIG. 118. — Side view of the sieve tube of a gourd stem : *pr*, protoplasm layer ; *u*, albuminous contents, forming mucilaginous strand.

the cell wall by osmosis? [56 (4).] The conducting cells are surrounded by a mass of strengthening fibers separating them from the parenchyma, *f*, and constituting with them a *fibrovascular bundle*. The larger vessels, *m*, *m'*, *a*, and *sp*, compose the *xylem*, the harder, more woody part of the bundle, and the smaller ones, *v*, *s*, the *phloëm*, or softer part. Notice also that there is no parenchyma in contact with the xylem and phloëm in the fibrovascular bundles of a monocotyl, to supply material for new growth, but they are entirely surrounded by a sheath of strengthening tissue, whence such bundles are said to be *closed*, and are incapable of further growth by the addition of new cells.

B. HERBACEOUS DICOTYLS

MATERIAL. — Young stems of sunflower, hollyhock, burdock, ragweed, cocklebur, castor bean, or any large herbaceous plant. In schools unprovided with compound microscopes, the minute anatomy can be studied with some degree of profit by the aid of pictures.

115. Gross anatomy. — Examine the outside of a young stem of sunflower, burdock, or other herbaceous dicotyl. Notice whether it is smooth, or roughened with hairs, scales, ridges, or grooves. If hairy, observe the nature of the hairs, whether bristly, downy, sticky, etc. Notice the color of the epidermis, whether uniform, or splotched or striped with other colors, as, for example, jimson weed, and pigweed (*amarantus*). If there are any buds, branches, or flower stems, notice where they originate ; what is the angle between the leaf and stem called? (100.)

Make a transverse cut through a portion of the stem that has stood for a time in coloring fluid and examine with a lens. Four regions can easily be distinguished : (1) the epidermis,

e, Fig. 119; (2) the primary cortex, c; (3) a ring of fibrovascular bundles, f; and (4) a central cylinder of parenchyma, p. In some specimens there will be a fifth region, the pith, which will appear in the section as a white circular spot in the center of the parenchyma.

In specimens a little older than the one shown in Fig. 119, a narrow circular line will be seen running through the ring of bundles nearly midway between their inner and outer extremities, connecting them into an unbroken circle around the central cylinder. This is the *cambium* layer, which supplies the vascular region with materials for new growth, and thus enables dicotyl stems to increase in diameter by the successive addition of fresh vascular rings from year to year.

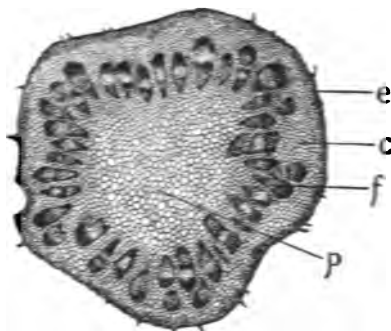
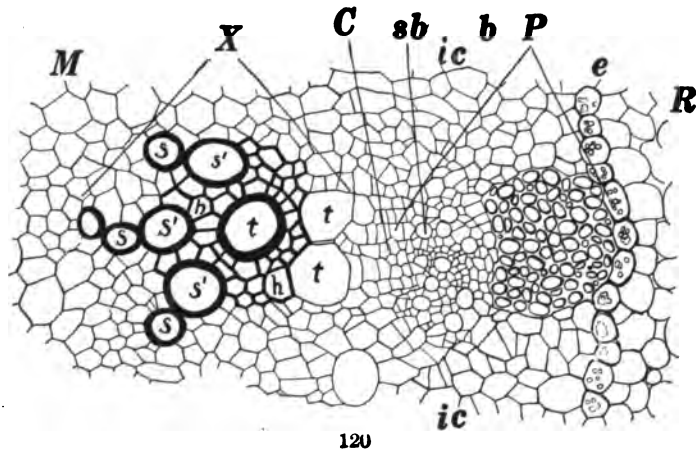


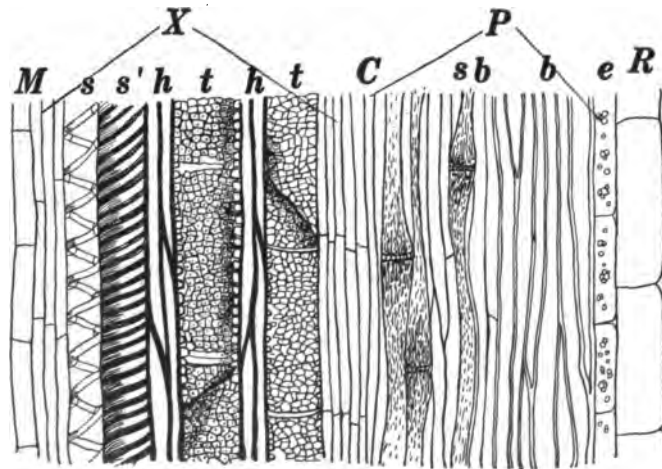
FIG. 119.—Transverse section of a very young stem of burdock, showing fibrovascular bundles not completely united into a ring: e, epidermis; c, primary cortex; f, a ring of fibrovascular bundles; p, central cylinder of parenchyma.

Examine in the same way a vertical section, and find the parts corresponding to those shown in Fig. 119. Make enlarged sketches of both sections, labeling the various parts observed.

116. Minute structure of a dicotyl stem.—Place successively under a high power of the microscope thin transverse and longitudinal sections of the stem just examined, or such other specimen as the teacher may provide. Bring one of the fibrovascular bundles into the field, and try to make out the parts shown in Figs. 120 and 121. The corresponding parts in the two sections are indicated by the same letters. Notice the cortex, *R*, on the outside and the pith, *M*, on the inside; between these, the cambium, *C*, the *xylem*, or woody tissue, included between the radiating lines *X*, and the newer tissues composing the *phloëm* between the lines *P*. The



120



121

FIGS. 120-121. — Transverse and longitudinal sections of a fibrovascular bundle in the stem of a sunflower. The two sections are lettered to correspond: *M*, pith (parenchyma); *X*, xylem region; *P*, phloem; *R*, cortex; *s*, spiral ducts; *s'*, annular ducts; *t*, pitted ducts; *C*, cambium between the phloem and xylem regions; *sb*, sieve tubes; *b*, bast; *e*, bundle sheath; *ic*, cambium (parenchyma) cells; *h*, wood fibers.

cambium and pith, which includes the medullary rays so conspicuous in perennial stems, are composed of live parenchyma cells, from which alone growth can take place; they are the active part of the stem. The xylem contains the large vessels, *t* and *s*, that convey water *up* the stem, together with the wood fibers, *h*. These are the permanent tissues. After completing their growth the cells of the xylem gradually lose their protoplasm, and all vitality ceases. Even the cell sap disappears, and sometimes the walls of the ducts are disintegrated, leaving a mere air space like that shown at *l* in Figs. 115 and 116. The dead cells and tissues, however, are by no means useless. They constitute the heartwood that is so valuable for timber, and serve an important purpose as a mechanical support for the stem. The phloëm contains on its outer face a mass of hard fibers, *b*, called bast, and toward the interior, the sieve tubes, *sb*, with a number of smaller vessels that convey *down* the stem the sap containing the food made in the leaves. It is separated from the cortex by the bundle sheath, *e*, and on its other side, from the exterior face of the xylem by the cambium, *C*. In this position the growing cambium adds new cells to the inner side of the phloëm, and to the outer side of the xylem, so that the former grows on its inner face and the latter on its outer. In perennial plants, as new rings are added to the xylem from season to season, the older ones die and are changed into heartwood, which thus gradually increases in thickness till in some of the giant redwoods and eucalypti, it may attain a diameter of thirty-five or forty feet. In the phloëm, on the other hand, as new cells are added from within, the older ones are gradually changed into hard bast, *b*, then into bark, and are finally sloughed off and fall to the ground. It is this free line of communication with the active cambium that enables dicotyl stems to grow on indefinitely, the sheath, *e*, being formed on the exterior face of the bundles only, leaving the other free, whence they are said to be *open*.

Make drawings of cross and vertical sections of a dicotyl

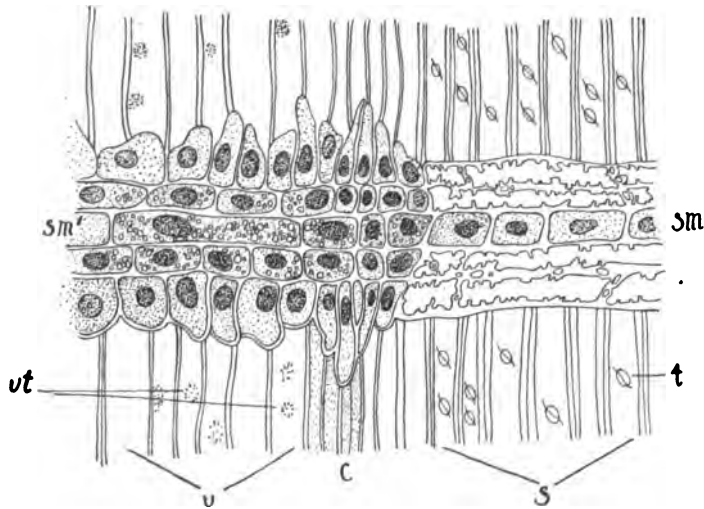


FIG. 122. — Internal structure of a pine stem, showing longitudinal section of a fibrovascular bundle through a medullary ray, *sm*, *sm'*: *s*, tracheids; *t*, bordered pits, surface view; *c*, cambium; *v*, sieve tubes; *vt*, sieve pits, analogous to the sieve plates in dicotyl stems.

stem as it appears under the microscope, labeling correctly all the parts observed. Show the shape and relative size of

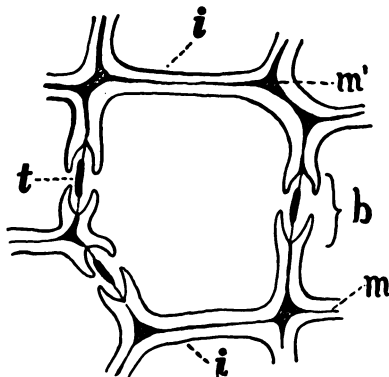


FIG. 123. — Internal structure of a pine stem, showing transverse section of a tracheid: *i*, cell walls; *m*, intermediate layer between walls of adjoining cells; *m'*, intercellular space here occupied by substance of intermediate layer; *b*, bordered pit in section at right angles to the surface; *t*, membrane for closing the pit canal.

the different cells. Compare your drawings with those made in your study of monocotyl stems, and write in your notebook the essential points of difference between the two.

117. The stems of conifers, the group of Gymnosperms to which the pine belongs, do not differ greatly from those of dicotyls, the chief difference being that the vascular bundles contain tracheids only, corresponding to the smaller vessels of

the phloëm, *s* and *s'*, shown in Fig. 121. These tracheids have large sunken places in their walls, called bordered pits (Fig. 123), closed by a very thin membrane through which water and dissolved food materials can more readily percolate. In all other essentials, the internal structure of pine stems is like that of dicotyls. (See Plate 5.)

C. WOODY STEMMED DICOTYLS

MATERIAL. — Elm, basswood, mulberry, leatherwood, and pawpaw show the bast well; sassafras, slippery elm, and (in spring) hickory and willow show the cambium; grape and trumpet vine, the ducts. Some of the specimens used should be placed in coloring fluid from 3 to 8 hours before the lesson begins. The rate at which the liquid is absorbed varies with the kind of stem and the season. It is more rapid in spring and slower in winter. If a cutting stands too long in the fluid, the dye will gradually percolate through all parts of it; care should be taken to guard against this.

118. The external layer. — While the primary structures, as shown in the last section, are essentially the same in all dicotyl stems, the continued yearly growth of perennials causes them to develop a number of secondary structures and variations of detail that differentiate them in a marked degree from soft-stemmed annuals. Take a piece of a three-year-old shoot of cherry, horse chestnut, or any convenient hardwood tree, and notice that the soft, green epidermis has given place to a thicker, harder, and usually darker colored bark. Notice the presence of lenticels (106) and their porous, corky texture for the admission of air to the interior. They are slightly raised above the surface of the bark, and are usually round, or more or less elongated in different directions, according as they are stretched vertically or horizontally by the growth of the axis. The characteristic mark-

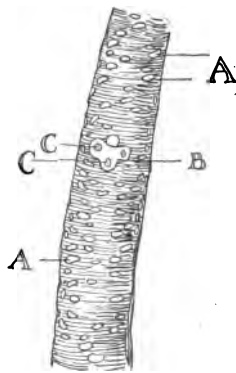


FIG. 124. — Part of a young China tree shoot, showing, *A*, lenticels; *B*, leaf scar; *C, C*, traces left by the broken ends of fibrovascular bundles that passed from the stem into the leaf. Natural size.



PLATE 5. — Stem of a conifer, *Sequoia gigantea*, Mariposa Grove, California. The first branch, 6 feet in diameter, leaves the parent trunk 125 feet above the ground. The photographer sitting on one of the exposed roots affords a good standard for comparison. The tree is noted for its massive limbs. The smaller trees in the background show the characteristic mode of branching in trees of this class.

ings of birch bark, which make it so ornamental, are due to the lenticels. In most trees they disappear on the older parts, where the bark is constantly breaking away and sloughing off.

119. Internal structures. — Cut a transverse section through your specimen, and notice under the epidermis a greenish layer of young bark; beneath this a layer of rather tough, stringy bast fibers, and beyond these a harder woody substance that constitutes the bulk of the interior; within this, at the very center of the axis, we find a cylinder of lighter texture, the pith, or medulla, occupying the place of the soft parenchyma which fills this space in very young stems.

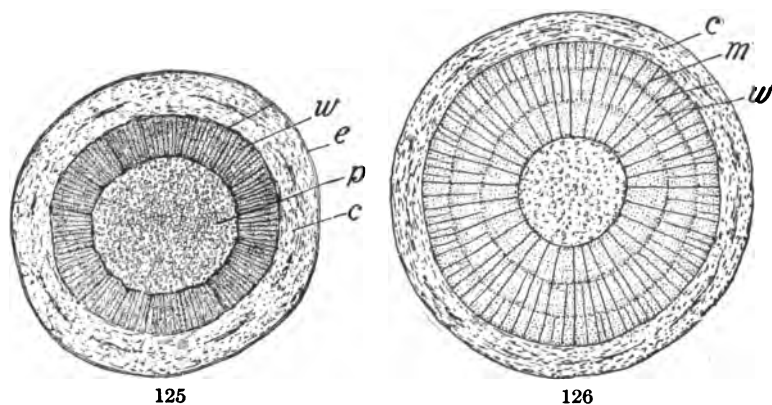
Between the woody axis and the bark notice a more or less soft and juicy ring.

120. The cambium layer. — This is not always easily distinguishable with a hand lens, but is conspicuous in the stems of sassafras, slippery elm, and aristolochia. If some of these cannot be obtained, the presence of the cambium can be recognized by observing the tendency of most stems to "bleed," when cut, between the wood and bark. The reason for this is because the cambium is the active part of the stem, in which growth is taking place, and consequently it is most abundantly supplied with sap. In spring, especially, it becomes so full of sap that if a rod of hickory or elder is pounded, the pulpy cambium is broken up and the bark may be slipped off whole from the wood.

121. Medullary rays. — Observe the whitish, silvery lines that radiate in every direction from the center, like the spokes of a wheel from the hub. These are the medullary rays, and consist of threads of pith that serve as lines of communication between the "central cylinder" and the growing cambium layer. In old stems the central pith frequently disappears and its office is filled by the medullary rays, which become quite conspicuous.

122. Structural regions of a woody stem. — Sketch cross and vertical sections of your specimen, as seen under the lens, labeling the different parts. Refer to Figs. 125, 126, if you

have any difficulty in distinguishing the parts. In a year-old shoot (Fig. 125), the structural regions correspond closely to those shown in Fig. 119, except that the ring of fibrovascular bundles is here compact and woody, and crossed by the radiating lines of the medullary rays. In a three-year-old shoot (Fig. 126), the main divisions are the same, but the soft parenchyma of the central cylinder is replaced by the pith, and the vascular ring is composed of three layers corresponding to the three years of growth. In general, mature



FIGS. 125, 126. — Cross sections of twigs: 125, section across a young twig of box elder, showing the four stem regions: *e*, epidermis, represented by the heavy bounding line; *c*, cortex; *w*, vascular cylinder; *p*, pith; 126, section across a twig of box elder three years old, showing three annual growth rings, in the vascular cylinder. The radiating lines (*m*), which cross the vascular region (*w*), represent the pith rays, the principal ones extending from the pith to the cortex (*c*). (From COULTER'S "Plant Relations.")

dicotyl stems may be said to include four well-defined regions: (1) the epidermis, or the bark; (2) the cortex, made up of bast and certain other tissues; (3) the cambium; (4) the woody vascular cylinder, made up of concentric rings, each representing a year's growth. The pith, or medulla, constitutes a fifth region, but is obvious only in young stems. Notice the little pores or cavities that dot the woody part in the cross section; where are they largest and most abundant? How are the rings marked off from one another?

These pores are the sections of ducts. They are very large in the grapevine, and a cutting two or three years old will show them distinctly. Examine sections of a twig that has stood in red ink from three to twelve hours, and observe the course the fluid has taken. How does this accord with the facts observed in your study of the conducting tissues in monocotyl and herbaceous stems? (111, 115, 116.)

123. The rings into which the woody cylinder is divided mark the yearly additions to the growth of the stem, which increases by the constant accession of new material to the outside of the permanent tissues (116). The cambium constantly advances outward, beginning every spring a new season's growth, and leaving behind the ring of ducts and woody fibers made the year before. As the work of the plant is most active and its growth most vigorous in spring, the largest ducts are formed then, the tissue becoming closer and finer as the season advances, thus causing the division into annual rings that is so characteristic of woody dicotyl stems. Each new stratum of growth is made up of the fibrovascular bundles that supply the leaves and buds and branches of the season. In this way we see that the increase of dicotyl trunks and branches is approximately in an elongated cone (Fig. 127), the number of rings gradually diminishing toward the top till at the terminal bud of each bough it is reduced to a single one, as in the stems of annuals.

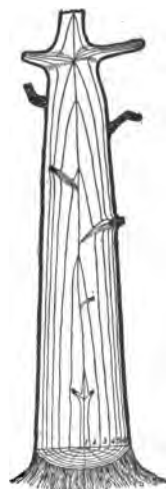


FIG. 127. — Diagram illustrating the annual growth of dicotyledons.

Sometimes a late autumn, succeeding a very dry summer, will cause trees to take on a second growth, and thus form two layers of wood in a single season. On this account we cannot always rely absolutely upon the number of rings in estimating the age of a tree, though the method is sufficiently exact for all practical purposes.

Practical Questions

1. Old Fort Moultrie near Charleston was built originally of palmetto logs; was this good engineering or not? Why? (113.)
2. Explain the advantages of structure in a culm of wheat; a stalk of corn; a reed. (113.)
3. Would the same quality be of advantage to an oak? Why, or why not?
4. Is it of any advantage to the farmer that grain straw is so light?
5. Explain why boys can slip the bark from certain kinds of wood in spring to make whistles. (120.)
6. Why cannot they do this in autumn or winter? (123.)
7. Name some of the plants commonly used for this purpose.
8. Is the spring, after the buds begin to swell, a good time to prune fruit trees and hedges? (120.)
9. What is the best time, and why?
10. Why are grapevines liable to bleed to death if pruned too late in spring? (120, 123.)
11. Why are nurserymen, in grafting, so careful to make the cambium layer of the graft hit that of the stock? (120.)
12. In calculating the age of a tree or bough from the rings of annual growth, should we take a section from near the tip, or from the base? Why? (123.)

IV. THE WORK OF STEMS

MATERIAL. — Leafy shoots of grape, balsam, peach, or other active young stems; a cutting of willow, currant, or any kind of easily rooting stem. Two bottles of water and some linseed or cottonseed oil.

EXPERIMENT 58. DO THE LEAVES HAVE ANY ACTIVE PART IN EFFECTING THE MOVEMENT OF SAP IN THE STEM? — Take two healthy young shoots of the same kind — grape, peach, corn, tropæolum, calla lily absorb rapidly. Trim the leaves from one shoot and close the cut surfaces with a little vaseline or gardener's wax to prevent loss of water by evaporation. Place the lower end of each in a glass jar or tumbler filled to the same height with water. Cut off *under water* a half inch from the bottom of each shoot, to get a fresh absorbing surface. This is necessary because exposure to air for even a second greatly hinders absorption by permitting the entrance of air into the severed ends of the ducts. Pour a little oil on the water in both jars to prevent evaporation. (Do not use kerosene; it is injurious to plants.) At the end of twenty-four hours, which vessel has lost the more water? How do you account for the difference?

EXPERIMENT 59. WHAT BECOMES OF THE WATER THAT GOES INTO THE LEAVES? — Cover the top of the vessel containing the leafy twig used in the last experiment with a piece of cardboard, having first cut a slit in one side, as shown in Fig. 128, so that it can be slid into place without injuring the stem. Invert over the twig a tumbler that has first been thoroughly dried, and leave in a warm, dry place. After an hour or two, what do you see on the *inside* of the tumbler? Where did the moisture come from?

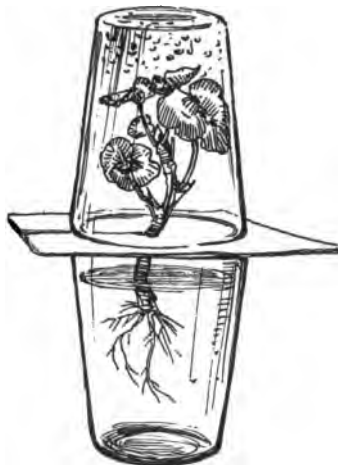


FIG. 128. — Experiment showing that moisture is thrown off by the leaves of plants.

EXPERIMENT 60. THROUGH WHAT PART OF THE STEM DOES THE SAP FLOW UPWARD? — Remove a ring of the cortical layer from a



FIG. 129. — A twig which had been kept standing in water after the removal of a ring of cortical tissue: *a*, level of the water; *b*, swelling formed at the upper denudation; *c*, roots.

twig of any readily rooting dicotyl, such as willow, being careful to leave the woody

part, with the cambium, intact. Place the end *below* the cut ring in water, as shown in Fig. 129. The leaves above the girdle will remain fresh. How is the water carried to them? How does this agree with the movement of red ink observed in 115 and 122?

EXPERIMENT 61. THROUGH WHAT PART DOES THE SAP COME DOWN? — Next prune away the leaves and protect the girdled surface with tin foil, or insert it below the neck of a deep bottle to prevent evaporation, and wait until roots develop. Do they come more abundantly from above or below the decorticated ring?

124. The three principal functions of the stem are: — (1) to serve as a mechanical support and framework for binding the other organs together and bringing them into the best attainable relations with light and air; (2) as a water carrier, or pipe line, for conveying the sap from the roots to the parts where it is needed; and (3) as a receptacle for the storage of foods.

125. Movement of water. — It has already been shown (71, 111) that a constant interchange of liquid is taking place through the stem, between the roots, where it is absorbed from the ground, and the leaves, where it is used partly in the manufacture of food. Just what causes the rise of sap in the stem is one of the problems of vegetable physiology that botanists



FIG. 130. — The stump of a large oak that was injured by lightning many years ago. The interior is completely decayed, leaving only a hollow shell of living tissue, from which branches continue to put forth leaves year after year.

have not yet been able to solve. There are, however, certain forces at work in the plant, which, though they may not account for all the phenomena of the movement, undoubtedly influence them to a great extent. From experiments 58–61, we can obtain an idea of what some of these forces may be.

126. Direction of the current. — These experiments show that the upward movement of crude sap toward the leaves is mainly through the ducts in the woody portion of the stem, while the downward flow of elaborated sap from the leaves takes place chiefly through the

soft bast and certain other vessels of the cortical layer. The action of the leaves in giving off part of the water absorbed, as shown in Exp. 59, probably has also an important influence on the course of sap movement. If loss of water takes place in any organ through growth or other cause, the osmotic flow of the thinner sap from the roots will set in that direction.

127. Ringing fruit trees. — The course of the sap explains why farmers sometimes hasten the ripening of fruit by the practice of *ringing*. As the food material cannot pass below the denuded ring, the parts above become gorged, and a process of forcing takes place. The practice, however, is not to be commended, except in rare cases, as it generally leads to the death of the ringed stem. The portion below the ring can receive no nourishment from above, and will gradually be so starved that it cannot even act as a carrier of crude sap to the leaves, and so the whole bough will perish.

128. Sap movement not circulation. — It must not be supposed that this flow of sap in plants is analogous to the circulation of the blood in animals, though frequently spoken of in popular language as the "circulation of the sap." There is no central organ like the heart to regulate its flow, and the water taken up by the roots does not make a continual circuit of the plant body as the blood does of ours, but is dispersed by a process of general diffusion, partly into the air through the leaves and partly through the plant body as food, wherever it is needed. Figure 131 gives a good general idea of the movement of sap in trees, the arrows indicating the direction of the movement of the different substances.

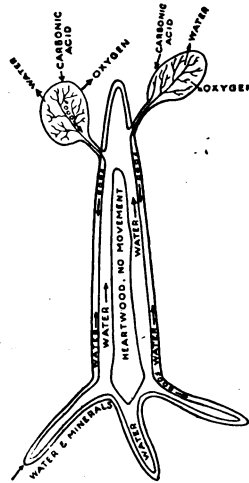


FIG. 131. — Diagram showing general movement of sap.

129. Unexplained phenomena. — Though the forces named above undoubtedly exert a powerful influence over sap movement, their combined action has not been proved capable of lifting the current to a height of more than 200 feet, while in the giant redwoods of California and the towering blue gums of Australia, it is known to reach a height of more than 400 feet. The active force exerted by the cell protoplasm has been suggested as an efficient cause, but as

the upward flow takes place through the cells of the xylem, which contain no protoplasm (116), this explanation is inadequate, and we must be content, in the present state of our knowledge, to accept the fact as one which science has yet to account for.

Practical Questions

1. Why will a leafy shoot heal more quickly than a bare one? (125, 126; Exp. 58.)
2. Why does a transverse cut heal more slowly than a vertical one? (126, 127.)
3. Why does a ragged cut heal less rapidly than a smooth one?
4. Why does the formation of wood proceed more rapidly as the amount of water given off by the leaves is increased? (126; Exp. 59.)
5. Why do nurserymen sometimes split the cortex of young trees in summer to promote the formation of wood? (116, 118.)
6. What is the advantage of scraping the stems of trees?
7. Explain the frothy exudation that often appears at the cut ends of firewood, and the singing noise that accompanies it. [120, 124 (2).]
8. Of what advantage is it to high climbing plants, like grape and trumpet vine (*Tecoma*), to have such large ducts? (111, 116, 122.)
9. Why is the process of layering more apt to be successful if the shoot is bent or twisted at the point where it is desired to make it root? (127; Exps. 60, 61.)
10. Why do oranges become dry and spongy if allowed to hang on the tree too long? (72, 126; Exps. 60, 61.)
11. Why will corn and fodder be richer in nourishment if, at harvest, the whole stalk is cut down and both fodder and grain are allowed to mature upon it? (126, 127; Exps. 60, 61.)
12. Why should we protect the south side rather than the north side of tree trunks in winter? (33.)
13. Why in pruning a branch is it best to make the cut just above a bud? (Exps. 60, 61.)
14. Why is the rim of new bark, or callus, that forms on the upper side of a horizontal wound, thicker than that on the lower side? (126, 127; Exps. 60, 61.)
15. Why is it that the medicinal or other special properties of plants are found mostly in the leaves and bark, or in the parts immediately under the bark? (120, 126.)
16. Why does twisting the footstalk of a bunch of grapes, just before ripening, make them sweeter? (127.)



PLATE 6. — A white oak, one of the monarchs of the dicotyl type. The owner of the ground on which this noble tree stands left a clause in his will bequeathing it in perpetuity a territory of 8 feet in every direction from its base. Refer to 89 and decide whether such an amount of standing room is sufficient to secure the preservation of this beautiful object.

17. Is it a mere superstition to drive nails into the stems of plum and peach trees to make them bear larger or more abundant fruit? (126, 127.)

18. Why is a living corn stalk heavier than a dry one? (124.)

19. Why is a stalk of sugar cane heavier than one of corn? Suggestion: Which is the heavier, pure water, or water holding solids in solution?

V. WOOD STRUCTURE IN ITS RELATION TO INDUSTRIAL USES

MATERIAL. — Select from the billets of wood cut for the fire, sticks of various kinds; hickory, ash, oak, chestnut, maple, walnut, cherry, pine, cedar, tulip tree, all make good specimens. Red oak shows the medullary rays well. Get sticks of green wood, if possible, and have them planed smooth at the ends. Collect also, where they can be obtained, waste bits of dressed lumber from a carpenter or joiner. If nothing better is available, any pieces of unpainted woodwork about the schoolroom will furnish subjects for study.

130. Detailed structure of a woody stem. — Select a good-sized billet of hard wood, and count the rings of annual growth. How old was the tree or the bough from which it was taken? Was its growth uniform from year to year? How do you know? Are the rings broader, as a general thing, toward the center or the circumference? How do you account for this? Is each separate ring of uniform thickness all the way round? Mention some of the circumstances that might cause a tree to grow less on one side than on the other. Are the rings of the same thickness in all kinds of wood? Which are the more rapid growers, those with broad or with narrow rings? Do you notice any difference in the texture of the wood in rapid and in slow growing trees? Which makes the better timber as a general thing, and why?

131. Heartwood and sapwood. — Notice that in some of your older specimens (cedar, black walnut, barberry, black locust, chestnut, oak, Osage orange, show the difference distinctly) the central part is different in color and texture from the rest. This is because the sap gradually abandons the center (116, 123) to feed the outer layers, where growth in dicotyls takes place; hence, the outer part of the stem

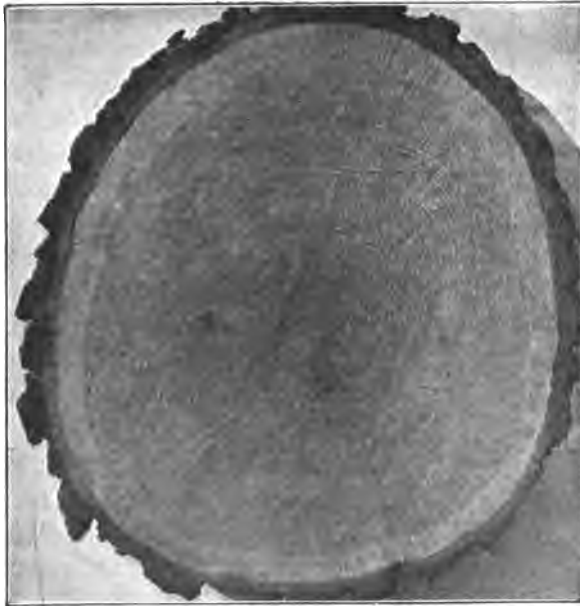


FIG. 132.—Cross section through a black oak, showing heartwood and sapwood. (*From* PINCHOT, U. S. Dept. of Agr.)

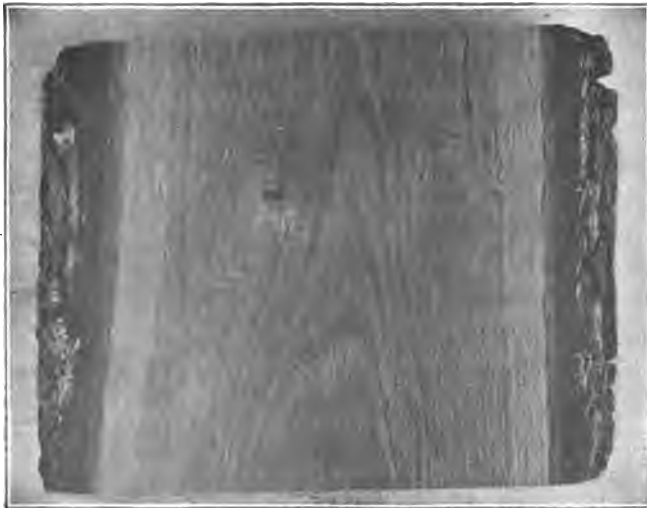
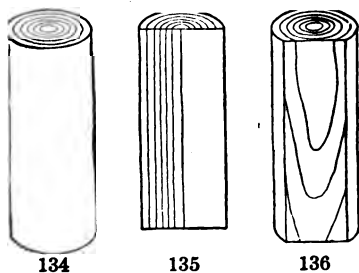


FIG. 133.—Vertical section through a black oak. (*From* PINCHOT, U. S. Dept. of Agr.)

usually consists of sapwood, which is soft and worthless as timber, while the dead interior forms the durable heartwood so prized by lumbermen. The heartwood is useful to the plant principally in giving strength and firmness to the axis. It will now be seen why girdling a stem, — that is, chipping off a ring of the softer parts all round, will kill it, while vigorous and healthy trees are often seen with the center of the trunk entirely hollow.

132. Different ways of cutting. — In studying the vertical arrangement of stems, two sections are necessary, a radial and a tangential one. The former passes along the axis, splitting the stem into halves (Fig. 135); the latter cuts between the

axis and the perimeter, splitting off a segment from one side (Fig. 136). The appearance of the wood used in carpentry and joiner's work is due largely to the manner in which the planks are cut.



FIGS. 134-136. — Diagrams of sections of timber: 134, cross section; 135, radial; 136, tangential. (From PINCHOT, U. S. Dept. of Agr.)

133. The cross cut. — The section seen at the end of a log (Figs. 132, 134) is called by carpenters a cross cut. It passes at right angles to the

grain of the wood, and severs what important structures? (116, 119, 122.) Examine a cross cut at the end of a rough plank, or the top of a stump or an old fence post, and tell why this kind of cut is seldom used in carpentry.

134. The tangent cut is so called because it is made at right angles to the

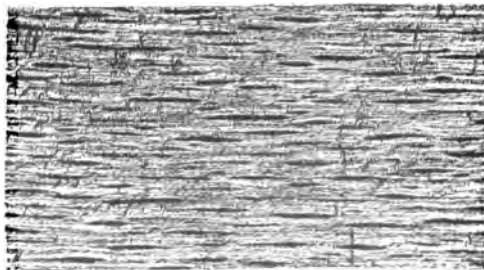


FIG. 137. — Tangential section of mountain ash, showing ends of the medullary rays.

radius of a log. Repeat the geometrical principle upon which such a cut is described as "tangential." It passes through the medullary rays and the annual rings diagonally (Fig. 136), and is the cheapest way of cutting timber, since the entire log is made into planks and there is no waste except the "slabs" and "edgings," as shown in Fig. 138. The cut ends of the medullary rays appear on the surface as small lines or slits (Fig. 137), and give to this kind of plank its peculiar grain-ing. The wavy or "watered" appearance of the annual rings (Figs. 133, 136, 140, 141), so often seen in cheap furniture and in the constructed houses, is caused by the strike striking them at various angles.

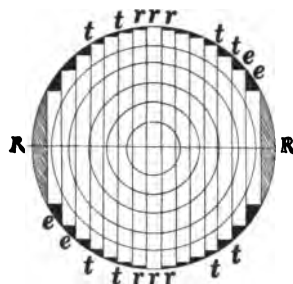


FIG. 138. — Diagram to show the common method of sawing a log. The circles represent rings of annual growth: R, R , diameter of the log; r, r, r and t, t, t , boards cut perpendicular to it, giving for the two or three central ones radial, for the others, tangential, cuts. The waste portions are the "slabs" and "edgings," shown in the dark segments at R, R , and the small triangular blocks, e, e, e .

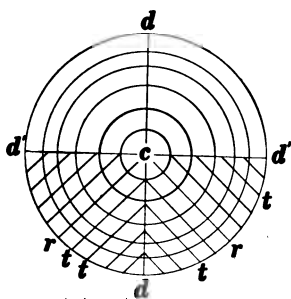


FIG. 139. — Diagram illustrating the "quartered" cut; d, d and d', d' , radial cuts (diameters) by which the log is "quartered"; c , center of the log; r, r , radii passing through the middle of each quarter, parallel to which the plan's t, t, t are cut. The circles represent rings of annual growth.

135. The radial, or quartered cut, familiar to most of us in the "quartered oak" of commerce, passes through the center of the log and cuts the rings of annual growth perpendicularly, giving it the "striped" appearance (Fig. 135) seen in the best woodwork. It gets its name from the practice of dealers in first sawing a log into quarters and then cutting parallel to the radius passing through the middle of each quarter, as shown in Fig. 139. In this way each cut strikes the rings perpendicularly, but except in the case of very large logs, only narrow

planks can be obtained in this manner. A better way of treating small logs is shown in Fig. 138, where the three central planks, *r,r,r*, on and near the diameter, will give the "quartered" effect, while the rest can be used for the cheaper tangential cuttings. Examine a piece of quartered board, or a log of wood that has been split down the center, and notice

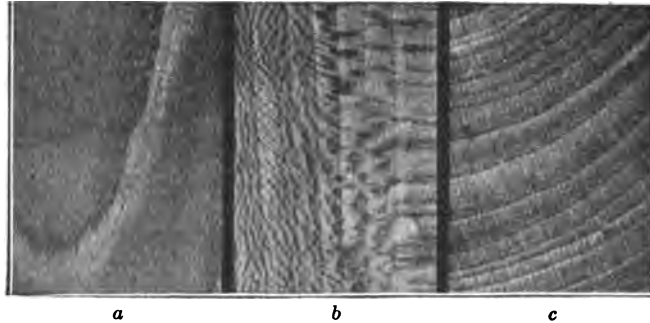


FIG. 140.—Sections of sycamore wood: *a*, tangential; *b*, radial; *c*, cross. (From PINCHOT, U. S. Dept. of Agr.)

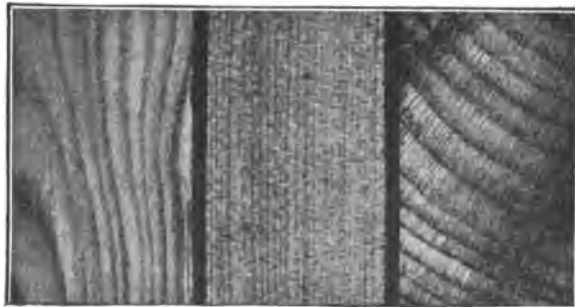


FIG. 141.—Section of white pine wood. (From PINCHOT, U. S. Dept. of Agr.)

that the medullary rays appear as silvery bands or plates (Figs. 140, 141). This is because the cut runs parallel to them. It is the medullary rays chiefly that give to commercial woods their characteristic graining. Knots, buds, and other adventitious causes also influence it in various degrees.

136. The swelling and shrinking of timber.—The capacity possessed by certain substances of bringing about an

increase of volume by the absorption of liquids is termed *imbibition*. Care must be taken not to confound imbibition with capillarity. (Exp. 53.) When liquids are carried into a body by capillary attraction, they merely fill up vacant spaces already existing between small particles of the substance, and therefore do not cause any swelling or increase in size. When imbibition takes place, the *molecules*, or chemical units of the liquid, force their way between those of the imbibing substance, and thus, in making room for themselves, bring about an increase in volume of the imbibing body. To this cause is due the alternate swelling and shrinking of timber in wet and dry weather.

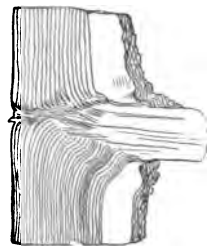
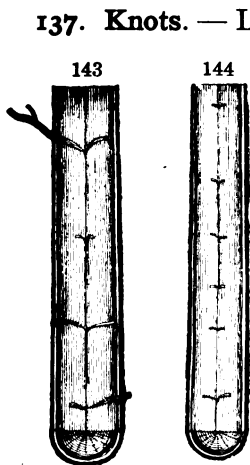


FIG. 142. — Section of tree trunk showing knot.



FIGS. 143-144. — Diagrams of tree trunks, showing knots of different ages: 143, from tree grown in the open; 144, from tree grown in a dense forest.

137. Knots. — Look for a billet with a knot in it. Notice how the rings of growth are disturbed and displaced in its neighborhood. If the knot is a large one, it will itself have rings of growth. Count them, and tell what its age was when it ceased to grow. Notice where it originates. Count the rings from its point of origin to the center of the stem. How old was the tree when the knot began to form? Count the rings from the origin of the knot to the circumference of the stem; how many years has the tree lived since the knot was formed? Does this agree with the age of the knot as deduced from its own rings? As the tree may continue to live and grow indefinitely after the bough which formed the knot

died or was cut away, there will probably be no correspondence between the two sets of rings, especially in the case of old knots that have been covered up and embedded in

the wood. The longer a dead branch remains on a tree the more rings of growth will form around it before covering it up, and the greater will be the disturbance caused by it. Hence, timber trees should be pruned while very young, and the parts removed should be cut as close as possible to the main branch or trunk. Sometimes knots injure lumber very much by falling out and leaving the holes that are often seen in pine boards. In other cases, however, when the knots are very small, the irregular markings caused by them add greatly to the beauty of the wood. The peculiar marking of bird's-eye maple is caused by abortive buds buried in the wood.

Practical Questions

1. Is the swelling of wood a physical or a physiological process?
2. Does wood swell equally with the grain and across it? (Suggestion: test by keeping a block under water for 10 to 20 days, measuring its dimensions before and after immersion.)
3. In building a fence, what is the use of "capping" the posts? (133.)
4. In laying shingles, why are they made to touch, if the work is done in wet weather, and placed somewhat apart, if in dry weather? (136.)
5. What is the difference between timber and lumber? Between a plank and a board? Between a log, stick, block, and billet?
6. Why does sapwood decay more quickly than heartwood? (131.)
7. Explain the difference between osmosis, diffusion, capillarity, and imbibition. (9, 56, 57, 136; Exp. 53.)

VI. FORESTRY

138. Practical bearings. — This part of our subject is closely related to lumbering and forestry. The business of the lumberman is to manufacture growing trees into merchantable timber, and to do this successfully he must understand enough about the structure of wood to cut his boards to the best advantage, both for economy and for bringing out the grain so as to produce the most desirable effects for ornamental purposes.

139. Forestry has for its object: (1) the preservation and cultivation of existing forests; (2) the planting of new



PLATE 7.—Timber tree spoiled by standing too much alone in early youth. Notice how the crowded young timber in the background is righting itself, the lower branches dying off early from overshadowing, leaving tall, straight, clean boles. (*From PINCHOT, U. S. Dept. of Agr.*)

ones, or the reforestation of tracts from which the timber has been destroyed. Forests may be either *pure*, that is, com-



FIG. 145.—After the forest fire.

posed mainly of one kind of tree, as a pine or a fir wood; or *mixed*, being made up of a variety of different growths, as are most of our common hardwood forests.

140. Enemies of the forest.—The first step in the preservation of our forests is to know the dangers to be guarded against. The chief of these are: (1) fires; (2) the ignorance or recklessness of man in cutting for commercial purposes;

(3) fungi; (4) injurious insects; (5) sheep, hogs, and other animals that eat the seeds and the young, tender growth.

141. How to protect the forests.—The annual destruction of forests by fires probably exceeds that from all other causes combined. The only effectual safeguard against this danger is watchfulness on the part of *everybody*. We can each one of us help in this work by at least being careful ourselves never to kindle a fire in the woods without taking every precaution against its



FIG. 146.—Oyster fungus on linden.

spreading. A single match, or the glowing stump of a cigar, carelessly thrown among dry leaves or grass, may start a conflagration that will destroy millions of dollars' worth of standing timber.

To prevent the spread of fungi, dead trees should be removed, and broken or decayed branches trimmed off and the cut surfaces painted. Birds which destroy insects should be protected; sheep and hogs should be kept out, and dead leaves left on the ground to cover the roots and fertilize the soil with the humus created by their decay. Finally, none but mature trees should be cut for industrial purposes, and the cutting ought to be done in such a way that the young surrounding growth will not be injured by the falling trunks.

142. The usefulness of forests. — Aside from the value of their products, forests are useful in many other ways. They influence climate beneficially by acting as windbreaks, by giving off moisture (Exp. 58), by shading the soil, and thus preventing too rapid evaporation. Their roots also help to retain the water in the soil, and by this means tend to prevent the washing of the land by heavy rains and to restrain the violence of freshets.

143. Forests and water supply. — It is especially important that the watershed of any region should be well protected by forests, to prevent contamination of the streams and to insure an unfailing supply of water by checking the escape of the rainfall from the soil.

Practical Questions

1. Explain the difference between a forest, grove, copse, wood, woodland.
2. In pruning a tree why ought the branch to be cut as close to the stock as possible? (137.)
3. Name the principal timber trees of your neighborhood. What gives to each its special value?
4. Name six trees that produce timber valuable for ornament; for toughness and strength.

5. Which is the better for timber, a tree grown in the open, or one grown in a forest, and why? (Plate 7.)
6. What are the objects to be attained in pruning timber trees? Orchard and ornamental trees?
7. Is the outer bark of any use to a tree, and if so, what?
8. Why should pruning not be done in wet weather? [140 (3), 141.]
9. Why should vertical shoots be cut off obliquely? [133, 140 (3), 141.]

Field Work

(1) Make a study of the various climbing plants of your neighborhood with reference to their modes of ascent, and the effect, injurious, or other, upon the plants to which they attach themselves. Note the origin and position of tendrils, and try to make out what modification has taken place in each case. Consider the twining habit in reference to parasitism, especially in the case of soft-stemmed twiners when brought into contact with soft-stemmed annuals. Observe the various habits of stem growth: prostrate, declined, ascending, etc., and decide what adaptation to circumstances may have influenced each case.

(2) Notice the shape of the different stems met with, and learn to recognize the forms peculiar to certain of the great families. Observe the various appliances for defense and protection with which they are provided, and try to find out the meaning of the numerous grooves, ridges, hairs, prickles, and secretions that are found on stems. Always be on the alert for modifications, and learn to recognize a stem under any disguise, whether thorn, tendril, foliage, water holder, rootstock, or tuber.

(3) Note the color and texture of the bark of the different trees you see and learn to distinguish the most important kinds:

- (a) scaly — peeling off annually in large plates, as sycamore, shagbark-hickory;
- (b) fibrous — detached in stiff threads and fibers, as grape;
- (c) fissured — split into large, irregular cracks by the growth of the stem in thickness, as oak, chestnut, and most of our large forest trees;
- (d) membranous — separating in dry films and ribbons, as common birch (*Betula alba*).

Observe the difference in texture and appearance of the bark on old and young boughs of the same species. Try to account for the varying thickness of the bark on different trees and on different parts of the same tree. Notice the difference in the timber of the same species when grown in different soils, at different ages of the tree, and in healthy and weakly specimens. Find examples of self-pruning trees (Plate 7), and explain how the pruning was brought about.

(4) Select a small plot, about a fourth of an acre, of any wooded tract in your neighborhood, and make a study of all the trees and shrubs it contains. Make a list of the different kinds, with the number of each. Take note of those that show themselves, by vigor and abundance of growth, best adapted to the situation. These are the "climax" or dominant vegetation of the plot. Find out, if you can, to what cause their superiority is due.



PLATE 8. — The American elm — a perfect type of deliquescent branching.

CHAPTER V. BUDS AND BRANCHES

I. MODES OF BRANCHING

MATERIAL. — For determinate growth, have twigs of an alternate and an opposite-leaved plant showing well-developed terminal buds: hickory, sweet gum, cottonwood, poplar, chestnut, are good examples of the first; maple, ash, horse-chestnut, viburnum, of the second; for the two-forked kind, mistletoe, buckeye, horse-chestnut, jimson weed, lilac. For showing indefinite growth: rose, willow, sumach, and ailanthus are good examples. Gummy buds, like horse-chestnut and poplar, should be soaked in warm water before dissecting, to soften the gum; the same treatment may be applied when the scales are too brittle to be handled without breaking. Buds with heavy fur on the scales cannot very well be studied in section; the parts must be taken out and examined separately.

144. Modes of branching. — Compare the arrangement of the boughs on a pine, cedar, magnolia, etc., with those of the elm, maple, apple, or any of our common deciduous trees. Draw a diagram of each, showing the two modes of growth. The first represents the *excurrent* kind, from the Latin *excurrere*, to run out; the second, in which the trunk seems to divide at a certain point and flow away, losing itself in the branches, is called *deliquescent*, from the Latin *deliquescere*, to melt or flow away.



FIG. 147. — Diagram of excurrent growth.



FIG. 148. — Diagram of deliquescent growth.

The great majority of stems, as a little observation will show, present a combination of the two modes.

145. Terminal and axillary buds.—Notice the large bud at the end of a twig of hickory, sweet gum, beech, cottonwood, etc. This is called the *terminal* bud because it terminates its branch. Notice the scars left by the leaves of the season as they fell away, and look for small buds just above them. These are *lateral*, or *axillary*, buds, so called because they spring from the axils of the leaves. How many leaves did your twig bear? What difference in size do you notice between the terminal and lateral buds?

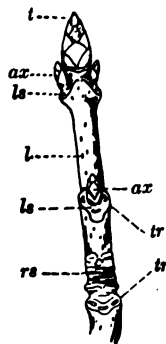


FIG. 149. — Winter twig of sugar maple: *t*, terminal bud; *ax*, axillary buds; *ls*, leaf scars; *tr*, leaf traces; *l*, lenticels; *rs*, ring of scars left by bud scales of preceding season.

146. The leaf scars.—Examine the leaf scars with a hand lens, and observe the number and position of the little dots in them. Ailanthus, varnish tree, sumach, and China tree show these very distinctly. They are called *leaf traces*, and mark the points where the fibrovascular bundles from the leaf veins passed into the stem. Look on the bark, or epidermis, for lenticels.

147. Bud scales and scars.—Notice the stout, hard scales by which the winter buds are covered in most of our hardy trees and shrubs. Remove these from the terminal one of your specimen, and notice the ring of scars left around the base. Look lower down on your twig for a ring of similar scars left from last year's bud. Is there any difference in the appearance of the bark above and below this ring? If so, what is it, and how do you account for it? Is there more than one of these rings of scars on your twig, and if so, how many? How old is the twig and how much did it grow each year? Has its growth been uniform, or did it grow more in some years than in others?

148. Arrangement and use of the scales.—Notice the manner in which the scales overlap so as to "break joints," like shingles on the roof of a house. Where the leaves are opposite, the manner of superposition is very simple. Re-

move the scales one by one, representing the number and position of the pairs by a diagram after the model given in Fig. 150. In the bud of an alternately branched twig the order will be different, and the diagram must be varied accordingly. Do you observe any difference as to size and texture between the outer and inner scales? Notice how the former inclose the tenderer parts within like a protecting wall. In cold climates the outer

scales are frequently coated with gum, as in the horse-chestnut, for greater security against the weather. The hickory and various other trees have the inner scales covered with fur or down that envelops the tender bud like a warm blanket.

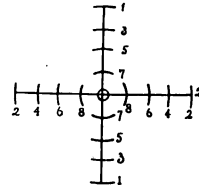


FIG. 150. — Diagram of opposite bud scales.



FIG. 151. — Development of the parts of the bud in the buckeye. (After GRAY.)

149. Nature of the scales. — The position of the scales shows that they occupy the place of leaves or of some part of a leaf. In expanding buds of the lilac and many other plants, they can be found in all stages of transition, from scales to true leaves. In the buckeye and horse-chestnut, they will easily be recognized as modified leaf stalks (Fig. 151). In the tulip tree, magnolia, India rubber tree, fig, elm, and many others, they represent appendages called *stipules*, often found at the bases of leaves. (See 165, 166.) In

this case a pair of scales is attached with each separate leaflet, and as the growing axis lengthens in spring, they are carried apart by the elongation of the internodes so that the scars are separated, a pair at each node, making rings all along the stem, as shown in Fig. 152, instead of having them compacted into bands at the base of

the bud. These scars are sometimes very persistent, and in the common fig and magnolia may often be traced on stems six to eight years old. Do they furnish any indication as to the relative age of the different parts of the stem, like the bands of scars on twigs of horse-chestnut and hickory? Give a reason for your answer. (Fig. 152.)

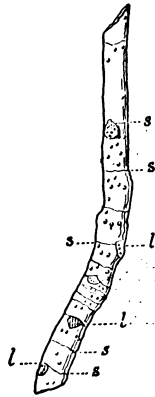


FIG. 152. — Stem of tulip tree: *s, s*, scars left by stipular scales; *l, l*, leaf scars.

150. Different rates of growth. — Notice the very great difference between branches in this respect. Sometimes the main stem will have lengthened from twenty to fifty centimeters or more in a single season, while some of the lateral ones will have grown but an inch or two in four or five seasons. One reason for this is because the terminal bud, being on the great trunk line of sap movement, gets a larger share of nourishment than the others, and being stronger

and better developed to begin with, starts out in life with better chances of success.

Make a drawing of your specimen, showing all the points brought out in the examination just made. Cut sections above and below a set of bud scars and count the rings of annual growth in each section. What is the age of each? How does this agree with your calculation from the number of scar clusters left by the bud scales?

151. Irregularities. — Take a larger bough of the same kind that you have been studying, and observe whether the arrangement of branches on it corresponds with the arrangement of buds on the twig. Did all the buds develop into branches? Do those that did develop all correspond in size and vigor? If all the buds developed, how many branches would a tree produce every year?

In the elm, linden, beech, hornbeam, hazelnut, willow, and various other plants, the terminal bud always dies and the one next in order takes its place, giving rise to the more or

less zigzag axis that generally characterizes trees of these species. (Fig. 153.)

152. Forked stems. — Take a twig of buckeye, horse-chestnut, or lilac, and make a careful sketch of it, showing all the points that were brought out in the examination of your previous specimen. Which is the larger, the lateral or the terminal bud? Is their arrangement alternate or opposite? What was the leaf arrangement? Count the leaf traces in the scars; are they the same in all? If all the buds had developed into branches, how many would spring from a node? Look for the rings of scars left by the last season's bud scales. Do you find any twig of more than one year's growth, as measured by the scar rings?

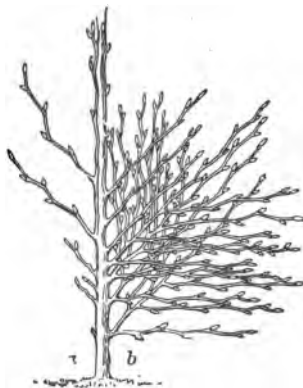


FIG. 153. — Bud development of beech: *a*, as it is, many buds failing to develop; *b*, as it would be if all the buds were to live.

Look down between the forks of a branched stem for a round scar. This is not a leaf scar, as we can see by its shape, but one left by the last season's flower cluster. The flower, as we know, dies after perfecting its fruit, and so a flower bud cannot continue the growth of its axis as other buds do, but has just the opposite effect and stops all further growth in that direction. Hence, stems and branches that end in a flower bud cannot continue to develop their main axis, but their growth is usually carried on, in alternate-leaved stems, by the nearest lateral bud, or in opposite-leaved ones, by the nearest pair of buds. In the first case there results the zigzag spray characteristic of such trees as the beech and elm (Fig. 155, *B*); in the second, the two-forked, or *dichotomous* branching,



FIG. 154. — Two-forked twig of horse-chestnut.

exemplified by the buckeye, horse-chestnut, jimson weed, mistletoe, and dogwood (Fig. 155, A).

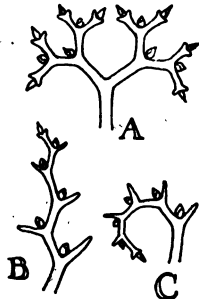


FIG. 155. — Diagrams of two-forked branching. The pointed bodies in the forks shows where terminal flower buds or flower clusters have changed the direction of growth.

Draw a diagram of the buckeye, or other dichotomous stem, as it would be if all the buds developed into branches, and compare it with your diagrams of excurrent and deliquescent growth. Draw diagrams to illustrate the branching of the elm, beech, lilac, linden, rose, maple, or their equivalents.

153. Definite and indefinite annual growth. — The presence or absence of terminal buds gives rise to another important distinction in plant development—that of *definite* and *indefinite* annual growth. Compare with any of the twigs just examined, a branch of rose, honey locust, sumac, mulberry, etc., and note the difference in their modes of termination. The first kind, where the bough completes its season's increase in a definite time and then devotes its energies to developing a strong terminal bud to begin the next year's work with, are said to make a *definite* or *determinate annual growth*. Those plants, on the other hand, which make no provision for the future, but continue to grow till the cold comes and literally nips them in the bud, are *indefinite*, or *indeterminate* annual growers. Notice the effect of this habit upon their mode of branching. The buds toward the end of each shoot, being the youngest and tenderest, are most readily killed off by frost or other accident, and hence new branches spring mostly from the older and stronger buds near the base of the stem. It is their mode of branching that gives to plants of this class their peculiar bushy aspect. Such shrubs generally make good hedges on account of their thick undergrowth. The same effect can be produced artificially by pruning.

154. Differences in the branching of trees.—We are now prepared to understand something about the causes of that endless variety in the spread of bough and sweep of woody spray that makes the winter woods so beautiful. Where the terminal bud is undisputed monarch of the bough, as in the pine and fir, or where it is so strong and vigorous as to overpower its weaker brethren and keep the lead, as in the magnolia, tulip tree, and holly, we have excurrent growth.



FIG. 156.—A mixed wood in winter, showing the trend of the branches.

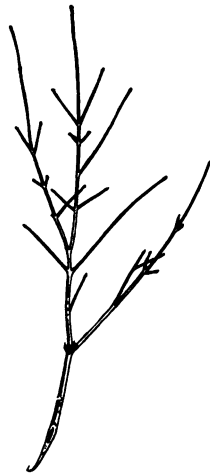


FIG. 157.—Winter spray of ash, an opposite-leaved tree.

In plants like the oak and apple, where all the buds have a more nearly equal chance, the lateral branches show more vigor, and the result is either deliquescent growth, or a mixture of the two kinds. In the elm and beech, where the usurping pseudo-terminal bud keeps the mastery, but does not completely overpower its fellows, we find the long, sweeping, delicate spray characteristic of those species. Examine a sprig of elm, and notice further that the flower buds are all down near the base of the stem, while the leaf buds are near the tip. The chief development of the season's growth is thus thrown toward the end of the branch, giving rise to that fine, feathery spray which makes the elm an even more beautiful object in winter than in summer (Fig. 158).

An examination of the twigs of other trees will bring out the various peculiarities that affect their mode of branching. The

angle, for instance, which a twig makes with its bough has a great effect in shaping the contour of the tree. Compare in this respect the elm and hackberry; the tulip tree and willow; ash and hickory. As a general thing, acute angles produce slender, flowing effects; right or obtuse angles, more bold and rugged outlines.

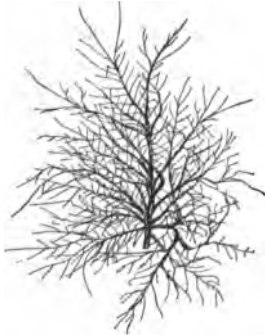


FIG. 158. — Winter spray of elm.

Practical Questions

1. Has the arrangement of leaves on a twig anything to do with the way a tree is branched? (145, 151, 152.)
2. Why do most large trees tend to assume the excurrent, or axial, mode of growth if let alone? (150, 154.)
3. If you wished to alter the mode of growth, or to produce what nurserymen call a low-headed tree, how would you prune it? (152, 153.)
4. Would you top a timber tree? (152, 153.)
5. Are low-headed or tall trees best for an orchard? Why?
6. Why is the growth of annuals generally indefinite?
7. Name some trees of your neighborhood that are conspicuous for their graceful winter spray.
8. Name some that are characterized by sharpness and boldness of outline.
9. Account for the peculiarities in each case.

II. BUDS

MATERIAL. — Expanding leaf and flower buds in different stages of development; large ones show the parts best and should be used where attainable. Some good examples for the opposite arrangement are horse-chestnut, maple, lilac, ash; for the alternate: hickory, sweet gum, balsam poplar, beech, elm. Where material is scarce, the twigs used in the last section may be placed in water and kept till the buds begin to expand.

155. Folding of the leaves. — Remove the scales from a bud of horse-chestnut nearly ready to open, and notice the manner in which the young leaves are folded. This is called *vernation*, or *prefoliation*, words meaning respectively “spring condition” and “condition preceding the leaf.” Leaves are packed in the bud so as to occupy the least space possible, and in different plants they will be found folded in a great



FIG. 159.—Expanding bud of English walnut, showing twice conduplicate vernation.

many different ways, according to the shape and texture of the leaf and the space available for it in the bud. When doubled back and forth like a fan, or crumpled and folded as in the buckeye, horse-chestnut, and maple, the vernation is *plicate* (Figs. 160, 162).



FIG. 160.—A partly expanded leaf of beech, showing plicate-conduplicate vernation.

156. Position of the flower cluster. — What do you find within the circle of leaves?

Examine one of the smaller axillary buds, and see if you find the same object within it. If you are in any doubt as to what this object is, examine a bud that is more expanded, and you will have no difficulty

in recognizing it as a rudimentary flower cluster. Notice its position with reference to the scales and leaves. If at the center of the bud, it will, of course, terminate its axis when the bud expands, and the growth of the branch will culminate in the flower. The branching of any kind of stem that bears a central flower cluster must, then, be of what order? Compare your drawings with the section of a hyacinth bulb or jonquil, and note the similarity in position of the flower clusters. In a bud of the hick-

161



162



FIGS. 161, 162.—Buds of maple: 161, vertical section of a twig; 162, cross section through bud, showing folded leaves in center and scales surrounding them.

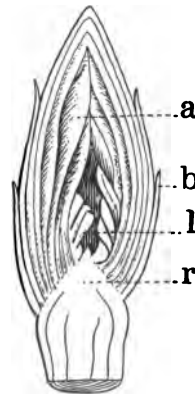


FIG. 163.—Vertical section of hickory bud: a, furry inner scales; b, outer scales; l, folded leaf; r, receptacle.

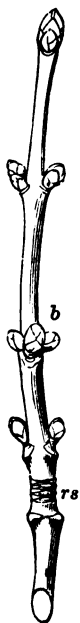


FIG. 164. — Twig of red maple, showing supernumerary bud, *b*; *rs*, ring of scars left by last year's bud scales. (After GRAY.)

ory, walnut, oak, etc., the position of the flower clusters is different from that of flowers in the buds of lilac and horse-chestnut. Look for a bud containing them, and find out where they occur. Can the axis continue to grow after flowering, in this kind of stem? Give a reason for your answer. Make sketches in transverse and longitudinal section (see Figs. 162, 163) of two different kinds of buds, illustrating the terminal and axillary position of the flower cluster.

157. Dormant buds. — A bud may often lie dormant for months or even years, and then, through the injury or destruction of its stronger rivals, or some other favoring cause, develop into a branch. Such buds are said to be *latent* or *dormant*. The sprouts that often put up from the stumps of felled trees originate from this source.

158. Supernumerary buds. — Where more than one bud develops at a node, as is so often the case in the oak, maple, honey locust, etc., all except the normal one in the axil are *supernumerary* or *accessory*. These must not be confounded with *adventitious* buds — those that occur elsewhere than at a node.

Practical Questions

1. Would protected buds be of any use to annuals? Why, or why not?
2. Of what use is the gummy coating found on the buds of the horse-chestnut and balm of Gilead? (148.)
3. Can you name any plants the buds of which serve as food for man?
4. How do flower buds differ in shape from leaf buds?
5. At what season can the leaf bud and the flower bud first be distinguished? Is it the same for all flowering plants?
6. Watch the different trees about your home, and see when the buds that are to develop into leaves and flowers the next season are formed in each species.

III. THE BRANCHING OF FLOWER STEMS

MATERIAL. — Typical flower clusters illustrating the definite and indefinite modes of inflorescence. Some of those mentioned in the text are: —

Indefinite: hyacinth, shepherd's purse, wallflower, carrot, lilac, blue grass, smartweed (*Polygonum*), wheat, oak, willow, clover.

Definite: chickweed, spurge (*Euphorbia*), comfrey, dead nettle, etc. Any examples illustrating the principal kinds of cluster will answer.

159. Inflorescence is a term used to denote the position and arrangement of flowers on the stem. It is merely a mode of branching, and follows the same laws that govern the branching of ordinary stems.

The stalk that bears a flower is called the *peduncle*. In a cluster the main axis is the common peduncle, and the separate flower stalks are *pedicels*. A simple leafless flower stalk that rises directly from the ground, like those of the dandelion and daffodil, is called a *scape* (Fig. 165).



FIG. 165. — Solitary terminal flower of a lily.

160. Two kinds of inflorescence. — The growth of flower stems, like that of leaf stems, is of two principal kinds, definite and indefinite, or, as it is frequently expressed, determinate and indeterminate. The simplest kind of each is the solitary, a single flower either terminating the main axis, as the tulip, daffodil, trillium, magnolia, etc., or springing singly from the axils, as the running periwinkle, moneywort, and cotton.



FIG. 166. — Indeterminate inflorescence of moneywort. (After GRAY.)

161. Indeterminate inflorescence is always axillary, since the production of a terminal flower would stop further growth in that direction and thus terminate the development



FIG. 167. — Raceme of milk vetch (*Astragalus*).

of the axis. The *raceme* is the typical flower cluster of the indefinite sort. In such an arrangement the oldest flowers are at the lower nodes, new ones appearing only as the axis lengthens and produces new internodes. The little scale or *bract* usually found at the base of the pedicel in flower clusters of this sort is a reduced leaf, and the fact that the flower stalk springs from the axil shows it to be of the essential nature of a branch. When the flowers are sessile and crowded on the axis in various degrees, the cluster produced may be a *spike*, as seen in the plantain, knotweed, etc., or a *head*, like that of the clover, buttonwood, and sycamore.

The *catkins* that form the characteristic inflorescence of most of our forest trees are merely pendant spikes. The *corymb* is a modification of the raceme in which the lower pedicels are elongated so as to place their flowers on a level with those of the upper nodes, making a convex, or more or less flat-topped cluster, as in the wall-flower and hawthorn. The *umbel* differs from the corymb in having the pedicels with their bracts all gathered at the top of the pe-



FIG. 168. — Catkins of aspen.

duncle, from which they spread in every direction like the rays of an umbrella, as the name implies. This is the prevalent type of flower cluster in the parsley family, which takes its botanical name, *Umbelliferae*, from



FIG. 169. — Corymb of plum blossoms.

its characteristic form of inflorescence. The pedicels of an umbel are called *rays*, and the circle of bracts at the base of the cluster is an *involucre*.



FIG. 170. — Umbel of milkweed.

162. Determinate, or cymose,

inflorescence. — In the *cyme*, the typical cluster of the determinate kind, the older blossoms in the center, being terminal, stop the axis of growth in that direction and force the stem, in continuing its growth, to send out side branches from the axils of the topmost leaves, in



FIG. 171. — Panicle of grass, a compound cluster of the racemose type.

a manner precisely similar to the two-forked branching of stems like the horse-chestnut and jimson weed. When the older peduncles are lengthened as described in 161, a flat-topped cyme is produced, which is distinguished from the corymb by its order of flowering, the oldest blossoms being at the



FIG. 172. — Flat-topped cyme of sneezeweed.

center, while in the corymb they appear in the reverse order. A peculiar form of cyme is found in the scorpioid

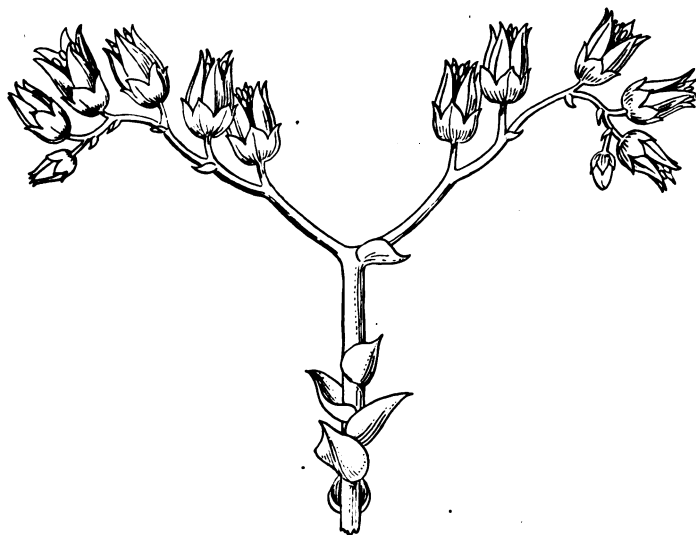
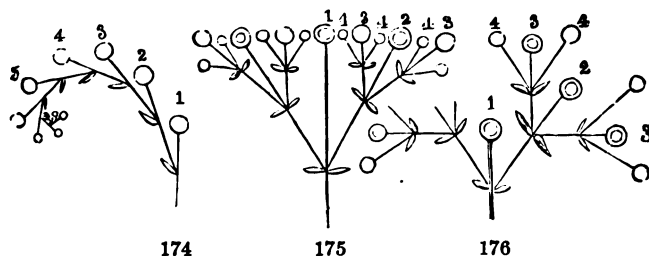


FIG. 173. — Scorpioid cyme.

or coiled inflorescence of the pink-root (*Spigelia*), heliotrope, comfrey, etc. Its structure will be made clear by an inspection of Figs. 174–176.



FIGS. 174–176. — Diagrams of cymose inflorescence, with flowers numbered in the order of their development: 174, cyme half developed (scorpioid); 175, a flat-topped or corymbose cyme; 176, development of a typical cyme.

163. The nature of flower stems. — A comparison of the types of inflorescence with the modes of branching in ordinary stems (144, 152, 153) will show a strict correspondence between them. Both bear leaves and buds, and the individual flowers of a cluster usually spring from the

axils of leaves or from bracts, which are merely reduced leaves. What, then, is the essential nature of flower stems?

164. Significance of the clustered arrangement. — As a general thing the clustered arrangement marks a higher stage of development than the solitary, just as in human life the rudest social state is a distinct advance upon the isolated condition of the savage. In plant life it is the beginning of a system of coöperation and division of labor among the associated members of the flower cluster, as will be seen later when we take up the study of the flower.

Practical Questions

1. Name as many solitary flowers as you can think of.
2. Do you, as a rule, find very small flowers solitary, or in clusters?
3. Would the separate flowers of the clover, parsley, or grape be readily distinguished by the eye among a mass of foliage?
4. Should you judge from these facts that it is, in general, advantageous to plants for their flowers to be conspicuous?

Field Work

(1) In connection with 144–154, the characteristic modes of branching among the common trees and shrubs of each neighborhood should be observed and accounted for. The naked branches of the winter woods afford exceptional opportunities for studies of this kind, which cannot well be carried on except out of doors. Note the effect of the mode of branching upon the general outline of the tree; compare the direction and mode of growth of the larger boughs with that of small twigs in the same species, and see if there is any general correspondence between them; note the absence of fine spray on the boughs of large-leaved trees, and account for it. Account for the flat sprays of trees like the elm, beech, hackberry, etc.; the irregular stumpy branches of the oak and walnut; the stiff straight twigs of the ash; the zigzag switches of the black locust, Osage orange, elm, and linden. Measure the twigs on various species, and see if there is any relation between the length and thickness of branches. Notice the different trend of the upper, middle, and lower boughs in most trees, and account for it. Observe the mode of branching of as many different species as possible of some of the great botanical groups of trees; the oaks, hickories, hawthorns, and pines, for instance, and notice whether it is, as a general thing, uniform among the species of the same group, and how it differs from that of other groups.

(2) In connection with 155-158, buds of as many different kinds as possible should be examined with reference to their means of protection, their vernation and leaf arrangement, and the resulting modes of growth. Compare the folding of the cotyledons in the seed with the vernation of the same plants, and observe whether the folding is the same throughout a whole group of related plants, or only for the same species. Notice which modes seem to be most prevalent. Select a twig on some tree near your home or your schoolhouse, and keep a record of its daily growth from the first sign of the unfolding of its principal bud to the full development of its leaves. Any study of buds should include an observation of them in all stages of development.

(3) With 160-165, study the inflorescence of the common plants and weeds that happen to be in season, until you have no difficulty in distinguishing between the definite and indefinite sorts, and can refer any ordinary cluster to its proper form. Notice whether there is any tendency to uniformity in the mode of inflorescence among flowers of the same family. Consider how each kind is adapted to the shape and habit of the flowers composing it, and what particular advantage each of the specimens examined derives from the way its flowers are clustered. In cases of mixed inflorescence, see if you can discover any reason for the change from one form to the other.

CHAPTER VI. THE LEAF

I. THE TYPICAL LEAF AND ITS PARTS

MATERIAL. — Leaves of different kinds showing the various modes of attachment, shapes, texture, etc. For stipules, leaves on very young twigs should be selected, as these bodies often fall away soon after the leaves expand. The rose, Japan quince, willow, strawberry, pea, pansy, and young leaves of beech, apple, elm, tulip tree, India rubber tree, magnolia, knotweed, furnish good examples of stipules. For the different orders of leaf arrangement, lilac, maple, spurge, trillium, cleavers (*Galium*) show the opposite and whorled kinds. Elm, basswood, grasses; alder, birch, sedges; peach, apple, cherry, show respectively for each group the three principal orders of alternate arrangement.

165. Parts of the leaf. — Examine a young, healthy leaf of apple, quince, or elm, as it stands upon the stem, and notice that it consists of three parts: a broad expansion called the *blade*; a leaf stalk or *petiole* that attaches it to the stem; and two little leaflike or bristle-like

bodies at the base, known as *stipules*. Make a sketch of any leaf provided with all these parts, and label them, respectively, blade, petiole, and stipules. These three parts make up a perfect or typical leaf, but as a matter of fact,

one or more of them is usually wanting.



FIG. 178. — Spiny stipules of clover.

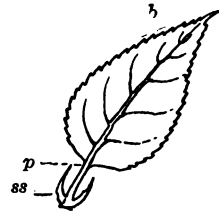


FIG. 177. — A typical leaf and its parts: *b*, blade; *p*, petiole; *ss*, stipules.

166. Stipules. — The office of stipules, when present, is generally to subserve in some way the purposes of protection. In many cases, as in the fig, elm, beech, oak, magnolia, etc., they appear only as protective scales that cover the bud during winter, and fall

away as soon as the leaf expands. When *persistent*, that is, enduring, they take various forms according to the purposes they serve. But under whatever guise they occur, their true nature may be recognized by their position on each side of the base of the petiole, and not in the *axil*, or angle formed by the leaf with the stem. (149.)

167. Leaf attachment. — The normal use of the petiole is to secure a better light exposure for the leaves, but, like other parts, it is subject to modifications, and is often wanting

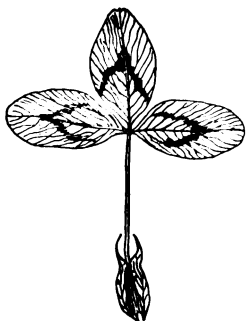


FIG. 179. — Adnate stipules of clover.



FIG. 180. — Leaves of smilax, showing stipular tendrils.



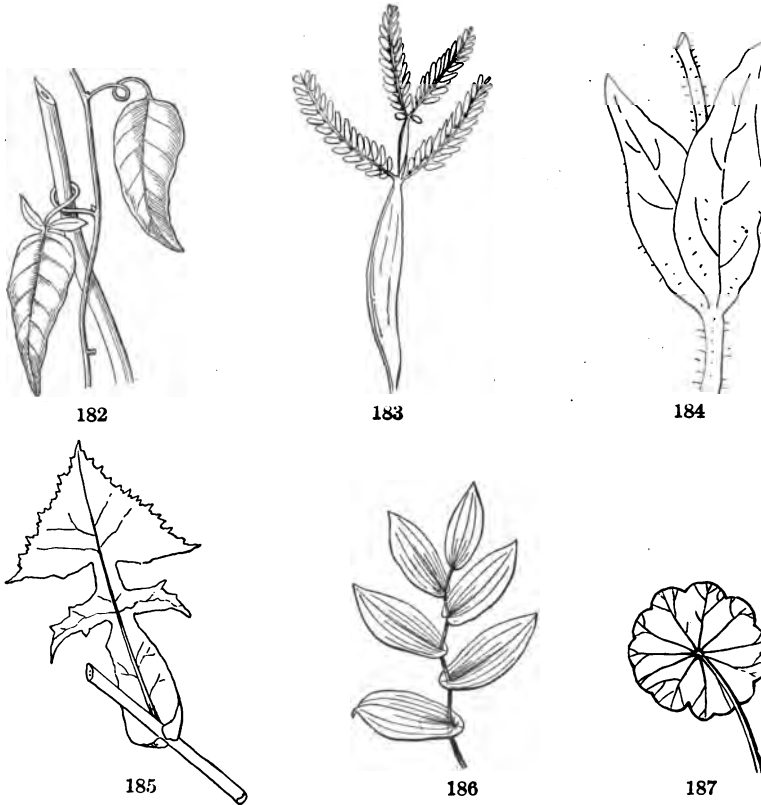
FIG. 181. — Leafy stipules of Japan quince.

altogether. In this case the leaf is said to be *sessile*, that is, *seated*, on the stem, and the leaf bases are designated by various terms descriptive of their mode of attachment. The meaning of these terms, when not self-explanatory, can best be learned by a comparison of living specimens with Figs. 184–187.

168. Arrangement of leaves on the stem. — The mode of attachment is something quite distinct from the mode of leaf arrangement on the stem, or *phyllotaxy*, as it is termed by botanists. It was seen in 148 that this takes place in two different ways, the alternate and opposite. These two kinds of arrangement represent the principal forms of leaf disposi-

tion on the stem, the different varieties of each depending on the manner in which the leaves are distributed.

Where three or more occur at a node, as in the trillium and cleavers (*Galium*), they constitute a whorl, which is only



FIGS. 182-187. — Petioles, and leaf attachment: 182, petioles of jasmine night-shade (*Solanum jasminoides*) acting as tendrils; 183, acacia, showing petiole transformed to leaf blade; 184, sessile leaves of epilobium; 185, clasping leaf of lactuca; 186, perfoliate leaves of uvularia; 187, peltate leaf of tropæolum. (182 and 186 after GRAY.)

a variant of the opposite arrangement. There is no limit to the number of leaves that may be in a whorl except the space around the stem to accommodate them.

The phyllotaxy of alternate leaves is more complicated.



FIG. 188.—Whorled leaves of Indian cucumber.

The different forms are characterized by the angular distance between the points of leaf insertion around the stem. In the elm, basswood, and most grasses, they are distributed in two rows or ranks on opposite sides of the stem, each just half way round the circumference from the one next in succession (Fig. 189), the third in vertical order standing directly over the first. In most of our common trees and shrubs five leaves are passed in making two turns round the stem, the sixth leaf in vertical order stand-

ing over the first. This is called the five-ranked arrangement, and is the most common order among dicotyls.

169. Relation between the shape and arrangement of leaves.

— Phyllotaxy is of importance chiefly on account of its influence on the light relation of leaves. A compact, close-ranked arrangement tends to shut off the light from the lower nodes, and hence, in plants where it prevails, the leaves are apt to be long and narrow in proportion to the frequency of the vertical rows. The yucca, oleander, Canada flea-



FIG. 189.—Twig of a hackberry (*Celtis cinerea*), showing the two-ranked arrangement. Notice how the position of the stems and branches of the main axis corresponds to that of the leaves.



PLATE. 9. — Vegetation of a moist, shady ravine. Notice the expanded surface of the leaf blades and the long internodes that separate the individual leaves. (From Rep't. Mo. Botanical Garden.)



FIG. 190. — Narrow leaves in crowded vertical rows.

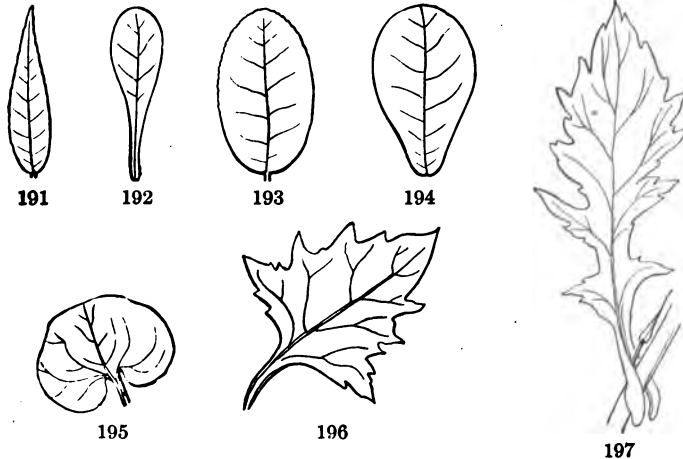
bane and bitterweed (*Helenium tenuifolium*), illustrate this relation.

On the other hand, when the leaves are large and rounded in outline, as those of the sunflower, hollyhock, and catalpa, they are usually separated by longer internodes, or their blades are cut and incised so that the sunlight easily strikes through to the lower ones.

170. Other external characteristics to be observed in leaves are: —

(1) General Outline: whether round, oval, heart-shaped, etc. (Figs. 191–197).

(2) Margins: whether unbroken (*entire*), or variously toothed and indented. (Figs. 198–202.)

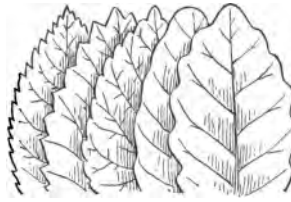


FIGS. 191–197. — Shapes of leaves: 191, lanceolate; 192, spatulate; 193, oval; 194, obovate; 195, kidney-shaped; 196, deltoid; 197, lyrate. (191–195 after GRAY.)

(3) Texture: whether thick, thin, soft, hard, fleshy, leathery, brittle.

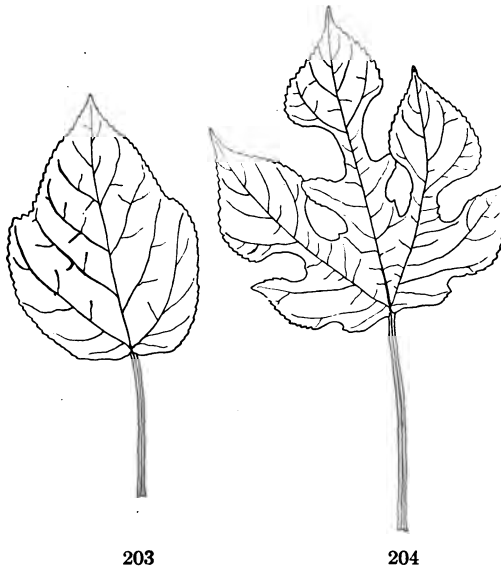
(4) Surface: smooth, shining, dull, wrinkled, hairy, or otherwise roughened.

Not only do leaves of different kinds exhibit these characteristics in varying degrees, but young and old leaves, or those on young and old plants of the same kind, often differ from each other in color, size, shape, texture, mode of attachment, and the like, to such a degree (Figs. 203, 204) that one not familiar with them in both stages would hardly recognize them as belonging to the same species.



198 199 200 201 202

FIGS. 198-202.—Margins of leaves: 198, serrate; 199, dentate; 200, crenate; 201, undulate; 202, sinuate. (After GRAY.)



203

204

FIGS. 203, 204.—Leaves of paper mulberry tree: 203, leaf from an old tree; 204, leaf from a two-year-old sprout.

The young leaves of eucalyptus, mulberry, and some oaks afford conspicuous examples of such differences, and they exist between the cotyledons and mature leaves of most plants.

Can you see any benefit, in the case of the plant whose leaves you are studying, that could be derived from such of the characteristics named above as they may exhibit?

Practical Questions

1. Tell the nature and use of the stipules in such of the following plants as you can find: tulip tree; fig; beech; apple; willow; pansy; garden pea; Japan quince (*Pyrus Japonica*); sycamore; rose; paper mulberry (*Broussonetia*).

2. How would you distinguish between a chinquapin, a chestnut, a chestnut oak, and a horse-chestnut tree by their leaves alone? By their bark and branches? Between a hickory, ash, common elder, box elder, ailanthus, sumach? Between beech, birch, elm, hackberry, alder?

(Any other sets of leaves may be substituted for those named, the object being merely to form the habit of distinguishing readily the differences and resemblances among those that bear some general likeness to one another.)

3. From the study of these or similar specimens, would you conclude that resemblances in leaves are confined to those of closely related kinds?

4. Name some causes independent of botanical relationship that might influence them. (169, 170; Exps. 48, 57.)

5. Do you find, as a general thing, more leaves with stipules or without?

6. Is their absence from a mature leaf always a sign that it is really exstipulate? (166.)

7. Can you trace any line of development through intervening forms from a merely sessile leaf, like that of the pimpernel or specularia, to a peltate one? (Figs. 184-187, and observation of living specimens.)

8. Does the leaf determine the position of the node, or the node the position of the leaf?

9. Strip the leaves from a twig of one order of arrangement and replace them with foliage from a twig of a different order; for instance, place basswood upon white oak, birch upon lilac, elm upon pear, honeysuckle upon barberry, etc. Is the same amount of surface exposed as in the natural order?

10. What disadvantage would it be to a plant if the leaves were arranged so that they stood directly over one another? (169.)

11. Why are the internodes of vigorous young shoots, or scions, generally so long? (150.)

12. If the upward growth of a stem or branch is stopped by pruning, what effect is produced upon the parts below, and why? (152, 153.)

13. Give some of the reasons why corn grows so small and stunted when sown broadcast for forage? (60, 63, 169.)

14. What is the use of "chopping" (*i.e.* thinning out) cotton?

II. THE VEINING AND LOBING OF LEAVES

MATERIAL. — Leaves of any monocotyl and dicotyl will show the difference between parallel and net-veining. To illustrate the palmate and pinnate kinds, the leaves of grasses and arums may be used for monocotyls, and for dicotyls, those of ivy, maple, grape, elm, peach, cherry, etc.; for division, examine lobed and compound leaves of as many kinds as are attainable. A specimen showing each kind of veining should be placed in

coloring fluid a short time before the lesson begins. The leafstalks of celery and plantain are excellent for showing the relation between the leaf veins and vascular system of the plant.

171. Parallel and net veining. — Compare a leaf of the wandering Jew, lily, or any kind of grass, with one of grape, ivy, or willow. Hold each up to the light, and note the veins or little threads of woody substance that run through it. Make a drawing of each so as to show plainly the direction and manner of veining. Write under the first, *parallel-veined*, and under the second, *net-veined*. This distinction of leaves into

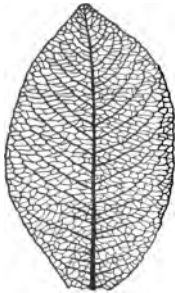


FIG. 206. — Net-veined leaf of a willow.

parallel and net-veined corresponds with the two great classes into which seed-bearing plants are divided, monocotyls, as a general thing, being characterized by the first kind, and dicotyls by the second.

172. Pinnate and palmate veining. —

Next, compare a leaf of the canna, calla lily, or any kind of arum, with one of the elm, peach, cherry, etc. What resemblances do

you notice between the two? What differences? Which is parallel-veined and which is net-veined? Make a drawing of each, and compare with the first two. Notice that in leaves of this kind, the petiole is continued in a large central vein, called the *midrib*, from which the secondary veins branch off on either side like the pinnæ of a feather; whence such leaves are said to be *pinnately*, or *feather veined*, as in Figs. 206, 207. In the cotton, maple, ivy, etc., on the other hand, the petiole breaks up at the base of the



FIG. 205. — Parallel-veined leaf of lily of the valley (After GRAY).



FIG. 207. — Pinnately parallel-veined leaf of calla lily (After GRAY).

leaf (Fig. 208) into a number of primary veins or ribs, which radiate in all directions like the fingers from the palm of the hand; hence, such a leaf is said to be *palmately* veined.

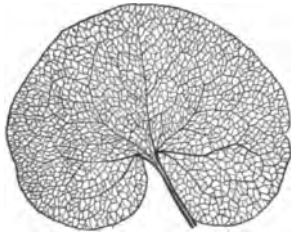


FIG. 208. — Palmately net-veined leaf of wild ginger.

Net-veined leaves — the plantain (Fig. 209), wild smilax, beech, dogwood — are sometimes ribbed in a way that might lead an inexperienced observer to confound them with parallel-veined ones, but the reticulations between the ribs show that they belong to the net-veined class.

173. Veins as a mechanical support. — Hold up a stiff, firm leaf of any kind, like the magnolia, holly, or India rubber, to the light, having first scraped away a little of the under surface, and examine it with a lens. Compare it with one of softer texture, like the peach, maple, or clover. In which are the veins the closer and stronger? Which is the more easily torn and wilted? Tear a blade of grass longitudinally and then crosswise; in which direction does it give way the more readily? Tear apart gently a leaf of maple, or ivy, and one of elm or other pinnately veined plant; in which direction does each give way with least resistance? What would you judge from these facts as to the mechanical use of the veins?



FIG. 209. — Ribbed leaf of plantain.

174. Effect upon shape. — By comparing a number of leaves of each kind it will be seen that the feather-veined ones tend to assume elongated outlines (Figs. 197, 207); the palmate-veined ones, broad and rounded forms (Figs. 195, 208). Notice also that the straight, unbroken venation of parallel-veined leaves is generally accompanied by smooth, unbroken margins, while the irregular, open meshes of net-veined leaves are favorable to breaks and indentations.

175. Veins as water carriers. — Examine a leaf from a stem that has stood in red ink for an hour or two. Do you see evidence that it has absorbed any of the liquid? Cut across the blade and examine with a lens. What course has the absorbed liquid followed? What use does this indicate for the veins, besides the one already noted? Observe the point of insertion on the stem, and examine the scar with a lens: do you see any evidence of a connection between the leaf veins and the fibrovascular bundles of the stem? (111, 125, 126. Notice where and how the veins end. Are they of the same size all the way, or do they grow smaller toward the tip? Are they separate and distinct, or are they connected throughout their ramifications, like the veins and arteries of the human body? How do you know? Do you see any of the coloring fluid in the small reticulations between the veins? How did it get there?

176. The nature and office of veins. — We learn from 173 and 175 that the veining serves two important purposes in the economy of the leaf: first, as a skeleton or framework, to support the expanded blade; and second, as a system of water pipes, for conveying the sap out of which its food is manufactured. In other words the veins are a continuation of the fibrovascular bundles into the leaves, by means of which the latter are put in communication with the body of the plant.

177. The relation between veining and lobing. — Compare the outline of a leaf of maple or ivy with one of oak or chrysanthemum. Do you perceive any correspondence between the manner of lobing or indentation of their margins, and the direction of the veins? (Figs. 210, 211.) To what class would you refer each one?

The lobes themselves may be variously cut, as in the fennel and rose geranium, thus giving rise to twice-cleft, thrice-cleft (Fig. 212), four-cleft, or even still more intricately divided blades.

178. Compound leaves. — Compare with the specimens just examined a leaf of horse-chestnut, clover, or Virginia



FIG. 210. — Pinnately lobed leaf of horse nettle.

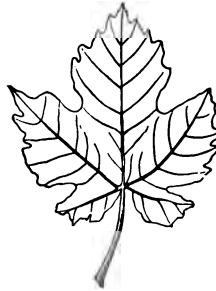


FIG. 211. — Palmately lobed leaf of grape.



FIG. 212. — Palmately parted leaf of a buttercup.

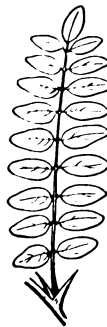


FIG. 213. — Pinnately compound leaf of black locust.



FIG. 214. — Palmately compound leaf of horse-chestnut.

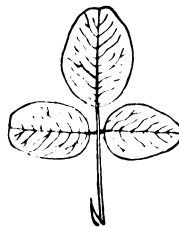


FIG. 215. — Pinnately trifoliate leaf of a desmodium.

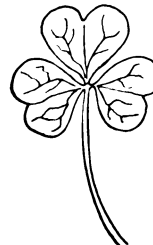


FIG. 216. — Palmately trifoliate leaf of wood sorrel.

creeper, and one of rose, black locust, or vetch. Notice that each of these last is made up of entirely separate divisions or leaflets, thus forming a *compound leaf*. Notice also that the two kinds of compound leaves correspond to the two kinds of veining and lobing, so that we have palmately and pinnately compound ones. In pinnate leaves the continuation of the common petiole along which the leaflets are ranged is called the *rhachis*.

Practical Questions

1. In selecting leaves for decorations that are to remain several hours without water, which of the following would you prefer, and why: smilax or Madeira vine (*Boussingaultia*); ivy or Virginia creeper; magnolia or maple; maidenhair or shield fern (*Aspidium*)? (173.)

2. Would you select very young leaves, or more mature ones, and why?

3. Can you name any parallel-veined leaves that have their margins lobed, or indented in any way?

4. Which are the more common, parallel-veined or net-veined leaves?

5. Why do the leaves of corn and other grains not shrivel lengthwise in withering, but roll inward from side to side? (173.)

6. Can you name any palmately veined leaves in which the secondary veins are pinnate? Any pinnately veined ones in which the secondary veins are palmate?

7. Lay one of each kind before you; try to draw a pinnate leaf with palmate divisions. Do you see any reason now why these so seldom occur in nature?

8. Name some advantages to a plant in having its leaves cut-lobed or compound. (169.)

9. Mention some circumstances under which it might be advantageous for a plant to have large, entire leaves. (169; Plate 9.)

10. How would the floating qualities of the leaves of the pond lily be affected if their blades were cut-lobed or compound?

11. Do the leaves of the red cedar and arbor vitæ contribute to their value as shade trees?

12. Name some of the favorite shade trees of your neighborhood; do they, as a general thing, have their leaves entire, or lobed and compound?

13. Which of the following are the best shade trees, and why: pine, white oak, mimosa (*Albizzia*), sycamore, locust, horse-chestnut, fir, maple, linden, China tree, cedar, ash?

14. Which would shade your porch best, and why: cypress vine, grape, gourd, morning-glory, wistaria, clematis, smilax, kidney bean, Madeira vine, rose, yellow jasmine, passion flower?

III. TRANSPIRATION

MATERIAL. — Leafy twigs of actively growing young plants. Sunflower, corn, peach, grape, calla, and arums in general transpire rapidly; thick-leaved evergreens and hairy or rough species, like mullein and horehound more slowly. For Exp. 63, small-leaved, large-leaved, and thick-leaved kinds will be needed.

APPLIANCES. — Glass jars and bottles with air-tight stoppers; a little vaseline, oil, gardener's wax, thread, cardboard, and a pair of scales.

EXPERIMENT 62. TO SHOW WHY LEAVES WITHER. — Dry two self-sealing jars thoroughly, by holding them over a stove or a lighted lamp for a short time to prevent "sweating." Place in one a freshly cut leafy sprig of any kind, leaving the other empty. Seal both jars and set them in the shade. Place beside them, but without covering of any kind, a twig similar to the one in the jar. Both twigs should have been cut at the same time, and their cut ends covered with wax or vaseline, to prevent access of air. Look at intervals to see if there is any moisture deposited on the inside of either jar. If there is none, set them both in a refrigerator or cover with a wet cloth and allow to cool for half an hour, and then examine again. In which jar is there a greater deposit of dew? How do you account for it? Take the twig out of the jar and compare its leaves with those of the one left outside; which have withered the more, and why?

EXPERIMENT 63. TO MEASURE THE RATE AT WHICH WATER IS GIVEN OFF BY LEAVES OF DIFFERENT KINDS. — Fill three glass vessels of the same size with water and cover with oil to prevent evaporation. Insert into one the end of a healthy twig of peach or cherry; into the second a twig of catalpa, grape, or any large-leaved plant, and into the third, one of magnolia, holly, or other thick-leaved evergreen, letting the stems of all reach well down into the water. Care must be taken to select twigs of approximately the same size and age, since the absorbent properties of very young stems are more injured by cutting and exposure than those of older ones. All specimens should be cut under water as directed in Exp. 58. Weigh all three vessels, and at the end of twenty-four hours, weigh again, taking note of the quantity of liquid that has disappeared from each glass. This will represent approximately the amount absorbed by the leaves from the twigs to replace that given off. Which twig has lost most? Which least? Note the condition of the leaves on the different twigs; have they all absorbed water about as rapidly as they have lost it? How do you know this? Pluck the leaves from each twig, one by one, lay them on a flat surface that has been previously measured off, into square inches or centimeters, and thus form a rough estimate of the area covered by each specimen. Make the best estimate

you can of the number of leaves on each tree, and calculate the number of kilograms of water it would give off at that rate in a day.

EXPERIMENT 64. THROUGH WHAT PART OF THE LEAF DOES THE WATER GET OUT? — Take some healthy leaves of tulip tree, grape, *tropeolum*, or any large, soft kind attainable. Cover with vaseline the *leafstalk* and *upper* surface of one; the stalk and *under* surface of a second; the stalk and *both* surfaces of a third, and leave a fourth one untreated. Suspend all four in a dry place by means of a thread attached to the petioles so that both surfaces may be equally exposed. The leaves must be all of the same species, and as nearly as possible of the same age, size, and vigor, and care must be taken that none of the vaseline is rubbed off in handling. Examine at intervals of a few hours. Which of the leaves withers soonest? Which keeps fresh longest? From what part would you conclude, judging by this experiment, that the water escapes most rapidly?

179. Transpiration, nutrition, and growth. — We learn from the foregoing, and from Exps. 58 and 59, that plants give off moisture very much as animals do by perspiration. The two processes must not be classed together, however, for they are physiologically different. The action, in plants, is called *transpiration*. It is usually assumed that a large amount of water must pass through the plant in order to bring to it the necessary supply of food material; but since the entrance of mineral salts is brought about by osmosis, conditioned by the living cells of the root; and since osmosis of salts may take place in a direction opposite to that of the greater movement of water, it follows that the entrance of salts is independent of transpiration.

Inasmuch, however, as a certain amount of water is necessary to bring the living cells into a condition of turgor (7) so that they may grow, it follows that there is a relation between transpiration and growth. If transpiration exceeds absorption for any length of time, the tissues will be depleted of their moisture, as is shown by the wilting of crops in dry, hot weather; and if the unequal movement continues long enough, the plant will die. Hence, a knowledge of the laws governing this important function is necessary to all who are interested in cultivating agricultural products.

180. Magnitude of the work of transpiration. — Few people have any idea of the enormous quantities of water given off by leaves. It has been calculated that a healthy oak may have as many as 700,000 leaves, and that 111,225 kilograms of water — equal to about 244,700 pounds — may pass from its surface in the five active months from June



FIG. 217. — A "weeping tree," showing the effect where absorption exceeds transpiration. Notice the position of the tree near the water where the roots have unlimited moisture. (After FRANCE.)

to October. At this rate 226 times its own weight may pass through it in a year, and it would transpire water enough during that time to cover the ground shaded by it to a depth of 20 feet!¹ Lawn grass gives off water at such a rate that a vacant lot of 150 × 50 feet, if well

turfed, would be capable of transpiring over a ton of water a day. Compare these figures with the average yearly rainfall in our Gulf States — 53 inches, approximately — and you can form some estimate of the injury done to a growing crop from this cause alone. The moisture is drawn from the surface by shallow rooted weeds (81) and dissipated through the leaves. In the case of forest trees the effect is different. Their roots, striking deep into the soil, draw up water from the lower strata and distribute it to the thirsty air in summer.

¹ Marshall Ward, "The Oak."

As the water given off by transpiration is in the form of vapor, it must draw from the plant the amount of heat necessary for its vaporization, and thus has the effect of making the leaves and the air in contact with them cooler than the surrounding medium. At the same time the coolness and moisture of the air tend to check the loss by evaporation from the surface soil. It is partly to this cause, and not alone to their shade, that the coolness of forests is due. Measurements at various weather bureau stations in the United States show that in summer the temperature of oak woods is 4° C. lower during the day than in the open, and as much higher at night. In a beech wood in Germany the difference between the forest and the general temperature amounted to as much as 7° C.

Practical Questions

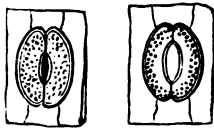
1. Is there any foundation in fact for the accounts of "weeping trees" and "rain trees" that we sometimes read about in the papers? (180; Exp. 48.)
2. Can you explain the fact, sometimes noticed by farmers, that in wooded districts, springs which have failed or run low during a dry spell sometimes begin to flow again in autumn when the trees drop their leaves, even though there has been no rain? (180; Exp. 63.)
3. Other things being equal, which would have the cooler, pleasanter atmosphere in summer, a well-wooded region or a treeless one? (180.)
4. Could you keep a bouquet fresh by giving it plenty of fresh air? (Exp. 62.)
5. Why does a withered leaf become soft and flabby, and a dried one hard and brittle? (7; Exp. 62.)
6. Why do large-leaved plants, as a general thing, wither more quickly than those with small leaves? (Exp. 63.)
7. Is the amount of water absorbed always a correct indication of the amount transpired? Explain. (179.)
8. Explain the difference between the withering caused by excessive transpiration and the shrinkage of cells due to plasmolysis. Are both of these physiological processes?
9. Why is it best to trim a tree close when it is transplanted? (179, 180.)
10. Why should transplanting be done in winter or very early spring, before the leaves appear? (180.)

IV. ANATOMY OF THE LEAF

MATERIAL. — For study of the epidermis, leaves of the white garden lily (*Lilium album*) are best, as the stomata can be seen on their lower surface with the naked eye. Wandering Jew, Spanish bayonet (*Yucca aloifolia*), anemone, narcissus, iris, canna, show them under a hand lens, but less distinctly. For sections, beet, mustard, and beech leaves may be used, or ready-mounted specimens obtained of a dealer.

A compound microscope is needed for a minute study of the leaf structure.

181. Stomata. — It was shown in Exp. 64 that the water of transpiration escapes most rapidly, as a general thing, from the under surface of leaves. To find out why this is so, a careful study of the epidermis will be necessary. For this purpose procure, if possible, the leaf of a white garden lily (*Lilium album*), wandering Jew, Spanish bayonet (*Yucca aloifolia*), anemone, narcissus, iris, or canna. The first-



218

219

FIGS. 218, 219. — Stomata of white lily leaf: 218, closed; 219, open. (After GRAY.)

named is preferable, as the transpiration pores can be seen on it with the naked eye. Examine the under surface with a hand lens, and you will see that it is covered with small eye-shaped dots like those shown in Figs. 218 and 219. Strip off a portion of the epidermis, hold it up to the light on a piece of moistened glass, and they can be seen quite clearly with a lens. These dots

are the pores through which the water vapor escapes in transpiration, and through which air finds its way into the tissues of the leaf. They are called *stomata* (sing., *stoma*), from a Greek word meaning “a mouth.” Look for stomata on the upper epidermis; do you find any, and if so, are there as many as on the under surface? Do you see any relation between this fact and the results obtained from Exp. 64? Can you see any good reasons why the stomata should be placed on the under side in preference to the upper? Are they as much exposed to excessive light and heat, or as liable to be choked by dust, rain, and dew here as on the upper side?

182. Distribution of stomata. — While stomata are generally more abundant on the under side of leaves, this is not always the case. In vertical leaves, like those of the iris, which have both sides equally exposed to the sun, they are distributed equally on both sides. In plants like the water lily, where the under surface lies upon the water, they occur only on the upper side. Succulent leaves, as a general thing, have very few, because they need to conserve all their moisture. Submerged leaves have none at all; why?

183. Minute study of a leaf epidermis.

— Place a bit of the lower epidermis of a leaf under the microscope, and examine with a high power. It will appear, if a monocotyl, to be composed of long, flat, rectangular spaces (Fig. 221); if the leaf of a dicotyl is used, they will be more or less irregular (Fig. 220), with the outlines fitting into each other like the tiling of a floor or the blocks of a Chinese puzzle.

These spaces are the cells of the epidermis, and the lines are the cell walls. Can you find any of the cell contents? The cell sap is not often visible; do you see the nuclei? Can you give a reason why the epidermal cells are so thin and flat? Between some of the cells you will see two kidney-shaped bodies placed with their concave sides together so as to leave a lenticular opening between them. This is a *stoma*, and the kidney-shaped bodies (Figs. 218, 219) are *guard cells*. They are given this name because they open or close the mouth of the stoma. If

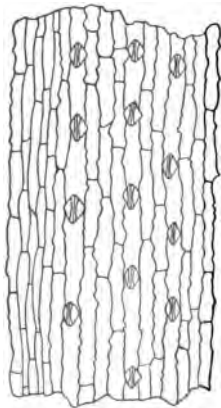


FIG. 221. — Under epidermis of an oat leaf, showing stomata.

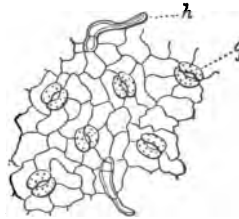


FIG. 220. — A small piece of the under epidermis of an oak leaf, highly magnified to show the stomata, *g*, and minute hairs, *h*.

you will imagine a toy balloon made in the form of a hollow ring, like the tire of a bicycle, you can easily see, from

Figs. 218, 219, that when the ring is strongly inflated, it will expand, and in enlarging its own circumference, will at the same time increase the diameter of the opening in the

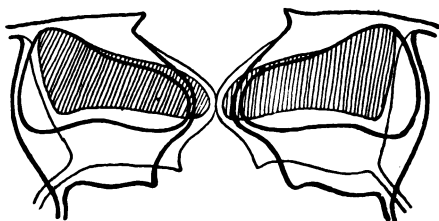


FIG. 222.—Outline of a stoma of hellebore in vertical section. The darker lines show the shape assumed by the guard cells when the stoma is open; the lighter lines, when the stoma is closed. The cavities of the guard cells with the stoma closed are shaded, and are distinctly smaller than when the stoma is open.

center. When the expansive force is removed, it collapses, thus closing, or greatly reducing, the aperture.

In the same way the guard cells, when there is abundance of water in them, expand, thus opening the stoma so that the water vapor passes out more readily. But when there is a dearth of

moisture, or when, by reason of chemical action in the soil, the roots fail to supply it, the leaves wither, the guard cells, losing their water, collapse, closing the pore, and transpiration is thus prevented or greatly retarded. (Fig. 222.)

Sketch a portion of the epidermis as it appears under the microscope, labeling the parts. If stomata can be found in both conditions, make sketches showing them both open and closed.

184. Internal structure of a leaf. — Roll a leaf blade, or fold it tightly to facilitate cutting, and with a scalpel, or a very sharp razor, cut the thinnest possible slice through the roll. This will give a section at right angles to the epidermis. It should be so thin as to appear almost transparent. Put a small bit of a section in a drop of water on a slide, place under the microscope, using a high power, and look for the parts shown in Fig. 223. Notice the horizontally flattened cells of the upper epidermis, *e*, and of the lower epidermis, *e'*; also the vertically elongated palisade cells, *p*, filled with particles of green coloring matter. These particles are the chlorophyll bodies, to which the green color of the leaf is due. They are the active agents in the manufacture of plant food, and in a leaf

removed from the plant during the day time and viewed under a high power, the chlorophyll bodies, on treatment

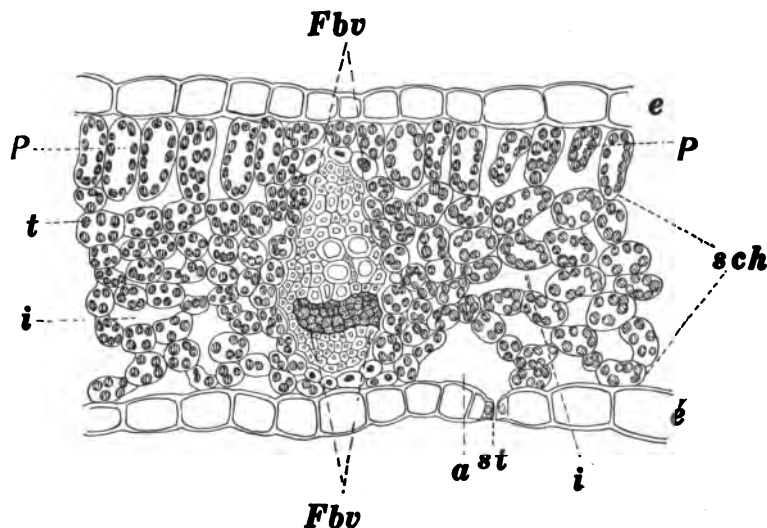


FIG. 223.—Transverse section through a leaf of beet: *e*, upper epidermis; *e'*, lower epidermis; *st*, stoma; *a*, air space; *p*, palisade cells; *t*, collecting cells; *sch*, spongy parenchyma; *i, i*, intercellular air spaces; *Fbv*, section of a vein (fibrovascular bundle).

with iodine, will be seen to contain granules of starch which they are in the act of elaborating. The collecting cells, *t*, receive the assimilated product from the palisade cells and pass it on through the spongy parenchyma, *sch*, to the fibrovascular bundles. Notice how much more abundant the green matter is in the upper part of the leaf than in the lower; has this anything to do with the deeper color of the upper surfaces of leaves? Notice the opening, *st*, in the lower epidermis; do you recognize it? (See Fig. 222.) It is a stoma, seen in vertical section. Notice the intercellular air spaces, *i, i*, in the spongy parenchyma, and the much larger one, *a*, just behind the stoma. Why is this last so much larger?



FIG. 224.—Chlorophyll bodies containing starch grains in the course of formation. Magnified 250 times.

Sketch the section of your specimen as it appears under the microscope. It will perhaps differ in some details from the one shown in the figure, but you can recognize and label the corresponding parts. Be sure that your drawing represents accurately the relative size and shapes of the different kinds of cells.

It is in the upper surface, where the chlorophyll particles abound, that the manufacture of food goes on most actively, and from the under surface, where the stomata are situated, that transpiration takes place and air and other gases pass to and from the interior. These facts have important bearings on the growth and external characters of leaves.

Practical Questions

1. Explain why a plant cannot thrive if its stomata are clogged with foreign matter. (179; Exp. 64; 184.)
2. Mention some of the ways in which this might happen. (181.)
3. Why must the leaves of house plants be washed occasionally to keep them healthy? (179, 181.)
4. Why is it so hard for trees and hedges to remain healthy in a large manufacturing town?

V. FOOD MAKING

MATERIAL. — A sprig of pondweed, mare's-tail (*Hippuris*), hornwort (*Ceratophyllum*), marsh St.-John's-wort (*Elodea*), or other green aquatic plant; bean or tropæolum, or other green leaves gathered from plants growing in the sunshine; a healthy potted plant; a small, fresh cutting.

APPLIANCES. — A shallow dish of water and two glass tumblers or wide-mouthed jars; a bent glass or rubber tube; a piece of black cloth or paper; a half pint of alcohol; iodine solution; a glass funnel or a long-necked bottle from which the bottom has been removed.

EXPERIMENT 65. IS THERE ANY RELATION BETWEEN SUNLIGHT AND THE GREEN COLOR OF LEAVES? — Place a seedling of oats, or other rapidly growing shoot, in the dark for a few days, and note its loss of color. Leave it in the dark indefinitely, and it will lose all color and die. Hence we may conclude that there is some intimate connection between the action of light and the green coloring matter of leaves.

EXPERIMENT 66. DO LEAVES GIVE OFF ANYTHING ELSE BESIDES WATER? — Submerge a green water plant, with the cut end uppermost, in

a glass vessel full of water, and invert over it a glass funnel, or a long-necked bottle from which the bottom has been removed as directed in Exp.

53. Expel the air from the neck of the funnel—or bottle—by submerging and corking under water so as to make it air-tight. Place in the sunlight and notice the bubbles that begin to rise from the cut end of the plant. When they have partly filled the neck of the funnel, remove the stopper and thrust in a glowing splinter. If it bursts into flame, or glows more brightly, what is the gas that was given off? (Exp. 22.)

As oxygen is not a product of respiration, some other process must be at work here, during which oxygen is set free, and some other substance used up. (Exps. 24 and 25.)

EXPERIMENT 67. WHAT IS THE SUBSTANCE TAKEN IN WHEN OXYGEN IS GIVEN OFF?— Fill two glass jars, or two tumblers, with water, to expel the air, and invert in a shallow dish of water, having first introduced a freshly cut sprig of some healthy green plant into one of them. Then, by means of a bent tube, blow into the mouth of each tumbler till all the water is expelled by the impure air from the lungs. Set the dish in the sunshine and leave it, taking care that the end of the cutting is in the water of the dish. After forty-eight hours remove the tumblers by running under the mouth of each, before lifting from the dish, a piece of glass well coated with vaseline (lard will answer), and pressing it down tight so that no air can enter.



FIG. 226. — Experiment for showing that leaves absorb carbon dioxide from the atmosphere.



FIG. 225. — Experiment showing that green plants give off oxygen in sunlight.

Place the tumblers in an upright position, keeping them securely covered. Fasten a lighted taper or match to the end of a wire, plunge it quickly first into one tumbler, then into the other, and note the result. What was the gas blown from your lungs into the jars? (Exps. 23, 24.) Why did the taper not go out in the second jar? What had become of the carbon dioxide?

EXPERIMENT 68. TO SHOW THAT LIGHT IS NECESSARY FOR A PLANT TO ABSORB CARBON DIOXIDE AND GIVE OFF OXYGEN.— Repeat Exp. 66, keeping the plant in a dark or shady place; do you see any bubbles? Test with a glowing match; is any oxygen

formed in the tube of the funnel? Move back into the sunlight and leave for a few hours; what happens when you thrust a glowing splinter into the tube?

EXPERIMENT 69. IS ANY FOOD PRODUCT FOUND IN LEAVES? — Crush a few leaves of bean, sunflower, or *tropæolum*, and soak in alcohol until all the chlorophyll is dissolved out. Rinse them in water, and soak the leaves thus treated in a weak solution of iodine for a few minutes, then wash them and hold them up to the light. If there are any blue spots on the leaves, what are you to conclude? If a test for sugar is to be made, use sap pressed from fresh leaves; for oils and fats, leaves should be dried without being placed in alcohol.



FIG. 227. — Leaf arranged with a piece of tin foil to exclude light from a portion of the surface.

EXPERIMENT 70. HAS THE PRESENCE OR ABSENCE OF LIGHT ANYTHING TO DO WITH THE OCCURRENCE OF STARCH IN LEAVES? — Exclude the light from parts of healthy leaves on a growing plant of *tropæolum*, bean, etc., by placing patches of black cloth or paper over them. Leave in a bright window, or preferably out of doors, for several hours, and then test for starch as in the last experiment; do you find any in the shaded spots?

EXPERIMENT 71. IS THE PRESENCE OF AIR NECESSARY FOR THE PRODUCTION OF STARCH? — Cover the blades and the petioles of several leaves with vaseline or other oily substance so as to exclude the air, and after a day or two test as before.

185. Influence of plants on the atmosphere. — These experiments show that leaves cannot do their work without light and air. The particular element of the atmosphere used by them in the process of food making is carbon dioxide. Their action in absorbing this gas and giving off oxygen tends to counterbalance the opposite action of respiration, decomposition, and combustion of all kinds, by which the proportion of it in the atmosphere tends to be constantly increased. In this way they help to regulate the quantity of it present and have a beneficial effect in ridding the air of one source of impurity.

186. Photosynthesis. — In our examination of the internal structure of the leaf, the chlorophyll bodies (184) were found to contain small granules of starch which the chlorophyll, under the stimulus of light, had elaborated as a nutriment for the plant tissues. Hence, the leaf may be regarded as a factory in which vegetable food, mainly starch, is manufactured out of the water brought up from the soil, and the carbon dioxide derived through the stomata from the atmosphere. In this process carbon dioxide (CO_2) is combined with water (H_2O) in such proportions that part of the oxygen is returned to the surrounding air. This is a fundamental food-forming process characteristic of green plants, and can take place only in the light. For this reason it has been named *Photosynthesis*, a word which means "building up by means of light," just as *photography* means "drawing or engraving by means of light."

In carrying on the operation of photosynthesis, sunshine is the power, the chlorophyll bodies the working machinery, carbon dioxide and water the raw materials, and starch or oil the finished product, while oxygen and the water of transpiration represent the waste or by-products.

187. How the new combination is effected. — It may seem strange that a gas and a liquid should combine to make something so different from either as starch, but their chemical constituents are the same in different proportions. Water is made up of 2 parts hydrogen and 1 part oxygen; carbon dioxide, of 1 part carbon and 2 parts oxygen, while starch contains carbon, hydrogen, and oxygen, in the ratios of 6, 10, and 5, respectively. Hence, by taking sufficient quantities of water and carbon dioxide and combining them in the proper proportions, the leaf factory can turn them into starch. If we use the letters C, H, and O, to represent Carbon, Hydrogen, and Oxygen, respectively, the new combination of materials can be expressed by an equation; thus: —



The water not used up in the process is given off as a waste product in transpiration, while the oxygen is returned to the air, as shown by Exp. 66. This equation is not to be understood as representing the chemical changes that actually take place in the leaf. These are too complicated, and at present too imperfectly known, to be considered here. It will serve, however, to give a fair idea of the final result from the process of photosynthesis, however brought about.

Simple as the operation appears, the chemist has not, as yet, been able to imitate it. He can analyze starch into its original constituents, but while he has the ingredients at hand in abundance, and knows the exact proportions of their combination, it is beyond his power, in the present state of our knowledge, to put them together. Hence, both man and the lower animals are dependent on plants for this most important food element. The so-called factories that supply the starch of commerce do not *make* starch any more than the miller makes wheat, but merely separate and render available for use that already elaborated by plants.

188. Proteins. — Foods of this class are mainly instrumental in furnishing material for the growth and repair of the tissues out of which the bodies of both plants and animals are built up. They embrace a great variety of substances, but their chemical nature is very complex and very imperfectly understood. Nitrogen is an important element in their composition, whence they are commonly distinguished as “nitrogenous foods.” Besides nitrogen, there are present carbon, hydrogen, oxygen, and sulphur, and traces of the mineral salts absorbed from the soil are found in varying quantities in the ash of different proteins. The percentages in which these ingredients are combined and the processes concerned in their formation are at present a matter of pure hypothesis. Botanists are not agreed even as to whether they are made in the leaf or in some other part or parts of the plant, though the weight of opinion inclines to the view that their construction takes place in the leaf.

189. The activities of leaves. — As there are only 4 parts of CO_2 to every 10,000 parts of ordinary free air, it has been estimated that in order to supply the leaf factory with the raw material it needs, an active leaf surface of one square meter — a little over one square yard — uses up, during every hour of sunshine, the CO_2 contained in 1000 liters (1000 quarts, approximately) of air. Suppose an oak tree to bear 500,000 leaves, each having a surface of 16 sq. cm., or 4 sq. in., and working 12 hours a day for 6 months in the year; you will then have some idea of the enormous quantity of air that passes each season through its leaf system. Add to this the almost incredible volume of water transpired in the same time (180), and we may well stand amazed at the tremendous activities of these silent workers that we are in the habit of regarding as mere passive elements in the general landscape.

190. The economic value of leaves. — Besides their importance as sanitary and food-making agencies, leaves have a direct commercial value as food products in the hay and fodder they supply for our domestic animals, the tea and salads with which they provide our tables, the aromatic flavors and seasonings contained in them, and the drugs, medicines, and dyes of various kinds for which they furnish the ingredients.

Practical Questions

1. Why do gardeners "bank" celery? (Exp. 65.)
2. Why are the buds that sprout on potatoes in the cellar, white? (Exp. 65.)
3. Why does young cotton look pale and sickly in long-continued wet or cloudy weather? (Exp. 65.)
4. Why do parasitic plants generally have either no leaves or very small, scalelike ones? (85, 186, 187.)
5. The mistletoe is an exception to this; explain why, in the light of your answer to question 4.
6. Could an ordinary nonparasitic plant live without green leaves? (186, 187.)
7. Are abundance and color of foliage any indication of the health of a plant? (186, 187; Exp. 65.)

8. Is the practice of lopping and pruning very closely, as in the process called "pollarding," beneficial to a tree under ordinary conditions? (186, 189; Exp. 63.)

9. Name some plants of your neighborhood that grow well in the shade.

10. Compare in this respect Bermuda grass and Kentucky blue grass; cotton and maize; horse nettle (*Solanum Carolinense*) and dandelion; beech, oak, red maple, dogwood, pine, cedar, holly, magnolia, etc.

11. Name all the aromatic leaves you can think of; all that are used as food, beverages, drugs, and dyes.

12. What is the use of aromatic and medicinal leaves to the plant itself? (Suggestion: Why does the housewife put lavender or tobacco leaves in her woolen chest?)

13. Which would be richer in nourishment, hay cut in the evening or in the morning, and why? (54, 186; Exp. 70.)

14. Mention three important sanitary services that are rendered by a tree like that shown in plate 6 or 8. (180, 185, 189.)

15. Name some of the plants employed in the manufacture of starch.

VI. THE LEAF AN ORGAN OF RESPIRATION

MATERIAL. — A number of vigorous, freshly cut green leaves; a liter or two (one or two quarts) of expanding flower or leaf buds.

APPLIANCES. — Some wide-mouthed jars of one or two liters' capacity; two small open vials of limewater.

EXPERIMENT 72. DO LEAVES GIVE OFF CARBON DIOXIDE? — Cover the bottoms of two wide-mouthed jars with water about two centimeters (1 inch) deep. Place in one a number of healthy green leaves with their stalks in the water, and insert among them a small open vial containing limewater. In the other jar place only a vial of limewater in the clear water at the bottom, this last being merely to make the conditions in both vessels the same. Seal both tight and keep together in the dark for about 48 hours, and then examine. In which jar does the limewater indicate the greater accumulation of CO_2 ? (It may show a slight milkiness in the other vessel due to gas derived from the inclosed air and water.) From this experiment, what process would you conclude has been going on among the leaves in jar No. 1? (Exp. 25.)

EXPERIMENT 73. IS THE EXHALATION OF CARBON DIOXIDE ACCOMPANIED BY ANY OTHER CONCOMITANT OF RESPIRATION? — In Exps. 24, 25, it was shown that respiration is accompanied by heat; hence, if the production of carbon dioxide by the leaf is due to this cause, it should be attended by the evolution of heat. To find out whether this is the case, partly fill a glass jar of two liters' capacity with unfolding leaf buds ar-

ranged in layers alternating with damp cotton batting or blotting paper (Fig. 228); close the jar tightly and leave from 12 to 24 hours in the dark to prevent the action of photosynthesis. Then insert a thermometer and note the rise in temperature. If a lighted taper is plunged in, it will quickly be extinguished, showing that respiration has been going on.

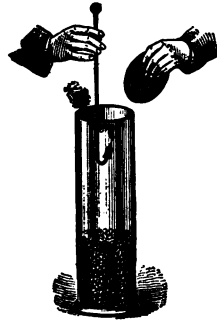


FIG. 228. — Arrangement of apparatus to show that heat and carbon dioxide are given off by leaf buds.

191. Respiration in leaves. — We see from experiments like the foregoing that the leaf, besides carrying on the functions of digestion, photosynthesis, and transpiration, is also an active agent in the work of respiration. In this function oxygen is used up and carbon dioxide given off, just as in the respiration of animals; but the process is so slow in plants that it is much more difficult to detect than the contrary action in photosynthesis, and is, in fact, not perceptible at all while the latter is going on, though it does not cease even then.

But while the leaf is the principal organ of respiration, the process is carried on in other parts of the plant as well, else it could not survive during the leafless months of winter. It *appears* to be most active at night, but this is only because it is not obscured then, as during the day, by the more active function of photosynthesis. Indeed, it was for a long time supposed that plants “breathed” only at night, and it was thought to be unwholesome to keep them in a bedroom. It is now known, however, that respiration goes on at all times and in all living parts of the plant, but the quantity of oxygen taken in is so small from a hygienic point of view that it may be disregarded.

192. Distinctions between respiration and photosynthesis. — While these two functions are contrasting and antipodal, so to speak, in their action, they are mutually complementary and interdependent, the one manufacturing food and the other using it up, or rather marking the activity of those

life processes by which it is used up. The difference between them will be made clear by a comparison of the two processes as summarized in the following statement:

PHOTOSYNTHESIS	RESPIRATION
Goes on only in sunlight and in the green parts of plants.	Goes on at all times and in all parts of the plant.
Produces starch and sugar.	Releases energy (heat and working power).
Gives off, as by-product, oxygen.	Gives off, as by-products, CO_2 and water.
A constructive process, in which energy is used up to make food.	A destructive, or consumptive process, in which food is used up in expending energy.

193. Metabolism. — The total of all the life processes of plants, including growth, waste, repair, etc., is summed up under the general term *metabolism*. It is a *constructive* or building-up process when it results in the making of new tissues out of food material absorbed from the earth and air, and the consequent increase of the plant in size or numbers. But, as in the case of animals, so with plants, not all the food provided is converted into new tissue, part being used as a source of energy, and part decomposed and excreted as waste. In this sense, metabolism is said to be *destructive*. The waste in healthy growing plants is always, of course, less than the gain, and a portion of the food material is laid by as a reserve store. For this reason, photosynthesis, being a constructive process, is usually more energetic than respiration, which is the measure of the destructive change of materials that attends all life processes.

It is evident also, from what has been said, that growth and repair of tissues can take place only so long as the plant has sufficient oxygen for respiration, since the energy liberated by it is necessary for the assimilation of nourishment by the tissues.

Thus we see that plants are dependent on air not only for respiration, but for nutrition, and none of their life processes can be carried on without it.

Practical Questions

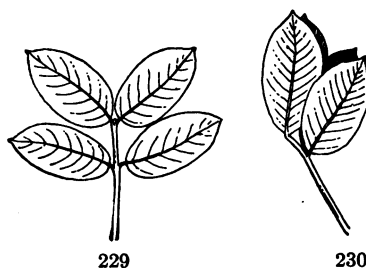
1. Can a plant be suffocated, and if so, in what ways? (87, 193; Exps. 26, 27.)
2. The roots on the palm shown in plate 3 are not drawing any sap from it as parasites; why does their continued growth bring about the death of the tree? (87, 193.)
3. Is it unwholesome to keep flowering plants in a bedroom? Leafy ones? Why, in each case? (191.)
4. Would there be any more reason for objecting to the presence of flowers by night than by day? Explain. (191.)
5. Why is respiration much less marked in plants than in animals? (30, 31.)

VII. THE ADJUSTMENT OF LEAVES TO EXTERNAL RELATIONS

MATERIAL. — A potted plant of oxalis, spotted medick, white clover, or other sensitive species. The subject is better suited for outdoor observation than for laboratory work.

EXPERIMENT 74. TO SHOW THAT LEAVES ADJUST THEMSELVES TO CHANGES IN INTENSITY OF LIGHT. — Keep a healthy potted plant of oxalis, white clover, or spotted medick in your room for observation. Note the daily changes of position the leaves undergo. Sketch one as it appears at night and in the morning.

In order to determine whether these changes are due to want of light or of warmth, put your plant in a dark closet in the middle of the day, without change of temperature. After several hours note results. Transfer to a refrigerator, or in winter place outside a window where it will be exposed to a temperature of about 5° C. (40° F.) for several hours, and see if any change takes place. Next put it at night in a well-lighted room and note the effect. If practicable, keep a specimen for several weeks in some place where electric lights are burning continuously all night, and watch the results.



FIGS. 229, 230. — Leaves of a peanut plant: 229, in day position; 230, in night position.

EXPERIMENT 75. TO SHOW THAT THE FALL OF THE LEAF MAY RESULT FROM OTHER CAUSES THAN COLD OR FROST. — Wrap some leaves of ailanthus, Kentucky coffee tree, ash, walnut, or hickory in a damp towel and

keep them in the dark for several days; the leaflets will fall away, leaving a clear scar like those on winter twigs.

EXPERIMENT 76. TO SHOW THAT ADJUSTMENTS TO TEMPERATURE MAY BE MADE BY CHEMICAL MEANS. — Place a small twig of oleander, laurustinus, or other broad-leaved evergreen in a 5 to 10 per cent solution of sugar, and transfer it at the end of a few days to a temperature of 6° to 8° below freezing. On comparison with a similar twig that has stood for the same length of time in pure water, it will be found to possess a greater power of resistance to cold.

194. The light relation. — The principal external conditions to which leaves have to adjust themselves are light, air, moisture, gravity, temperature, and the attacks of animals. From the knowledge of their work and function gained in the preceding sections, it will be clear that the primary relation of the leaf is a light relation, and to this, first of all, it must adjust itself.

It was shown in Exps. 56 and 57 how promptly leaves respond to changes in the direction of light, and a little observation (Exp. 74) will convince us that they are equally sensitive to changes in intensity and periodicity of illumination.



FIG. 231. — A plant that has been growing near an open window, showing the leaves all turned toward the light.

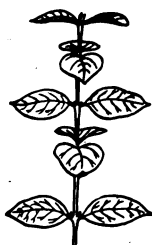
195. Phototropism. — The movement of plants in response to light is called *phototropism* — a word that means “turning toward or away from light.” It includes all kinds of light adjustments, and examples of it are to be met with everywhere in the disposition of leaves with reference to their light exposure.

196. Horizontal and vertical adjustment. — Take two sprigs, one upright, the other horizontal, from any convenient shrub or tree — and notice the difference in the position of the leaves. Examine their points of attachment and see how this is brought about, whether by a twist of the petiole or of the base of the leaf blades, or by a half twist of the stem between two consecutive leaves, or by some other means.



PLATE 10. — A mosaic of moonseed leaves, showing adjustment for light exposure.
(From Mo. Botanical Garden Rep't.)

Observe both branches in their natural position; what part of the leaf is turned upward, the edge or the surface of the blade? Change the position of the two sprigs, placing the vertically growing one horizontal, and the horizontal one vertical. What part of the leaves is turned upward in each?



232



233

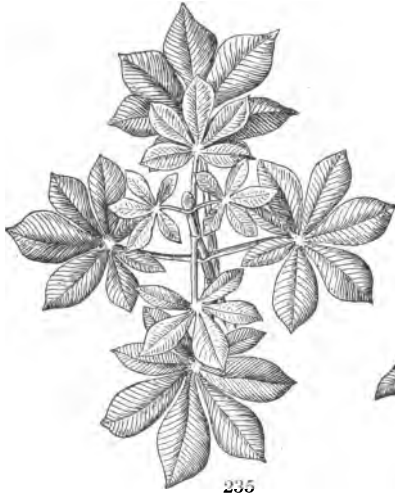
FIGS. 232, 233. — Adjustment of leaves to different positions: 232, upright; 233, procumbent.

197. Leaf mosaics. — Trees with horizontal or drooping branches, like the elm and beech, and vines growing along walls or trailing on the ground, generally display their foliage in flat, spreading layers, each leaf fitting in between the interstices of the others like the stones in a mosaic, whence this has been called the *mosaic* arrangement. (Plate 10.) In plants of more upright or bunchy habit, the leaves are placed at all angles, giving the appearance of a rosette when viewed from above, whence this is called the *rosette* arrangement.



FIG. 234. — Leaf mosaic of elm.

A variety of the same disposition is seen in the pyramidal shape assumed by plants with large, undivided leaves like the mullein and burdock (Fig. 237), in which access of light is secured by a mutual adjustment between the size and position of leaves, the upper ones becoming successively smaller.



235



236

FIGS. 235, 236.—Horse-chestnut leaves: 235, leaf rosette seen from above; 236, the same seen sideways, showing the formation of rosettes by the lengthening of the lower petioles.

blossoms to face the sun. If you live where cotton is grown, notice the leaves in a field about ten o'clock on a bright sunny morning, and again from the same point of view at about four or five in the afternoon. Do you perceive any difference in their general disposition? Watch on a cloudy day and see if any change takes place. Find out by observation whether the "heliotrope" of the hothouses is really heliotropic.



FIG. 237.—Leaf pyramid of mullein.

199. Adjustment against too great intensity of light.—Plants frequently have to protect themselves against excess of light and heat. An



238

239

FIGS. 238, 239.—A compass plant, rosinweed (*Silphium laciniatum*): 238, seen from the east; 239, seen from the south.

interesting example of this kind of adjustment is furnished by the rosinweed, or compass plant (*Silphium laciniatum*, Figs. 238, 239), which grows in the prairies of Alabama and westward, where it is exposed to intense sunlight. The leaves not only stand vertical, but have a tendency to turn their edges north and south so that the blades are exposed only to the gentler morning and evening rays. The prickly lettuce manifests the same habit in a less marked degree.

200. Night and day adjustments.—These are movements in response to changes in the degree of illumination and temperature, as evidenced by the fact that they become feeble and soon cease altogether if the plant is kept a sufficient time under uniform conditions as to these two factors. (Exp. 74.) They are called “nyctitropic” or sleep movements, because they are most obvious in certain plants that undergo periodic adjustments to the alternations of day and night suggestive of an imaginary likeness to the sleep of animals.

Examples are most frequently met with among members of the pea family (*Leguminosæ*), the spurges (*Euphorbiaceæ*), and the sorrel (*Oxalis*) family. They are found among other species also, and indeed are much more general than is usually supposed, most plants showing signs of them if carefully tested. A simple way of doing this



240 241
FIGS. 240, 241.—A plant of the guayule (*Parthenium argentatum*), to the leaves of which indexes have been affixed to show their day and night position: 240, day position; 241, night position. (From photographs by Prof. F. E. Lloyd.)

is by attaching bristles about two inches long to the tips of two leaves on opposite sides of the stem, as in Figs. 240, 241, and comparing the divergence of the bristles during the day and at nightfall. In this way a change of position in the

leaves, too slight to attract attention otherwise, will be made apparent. The positions assumed vary in different plants,



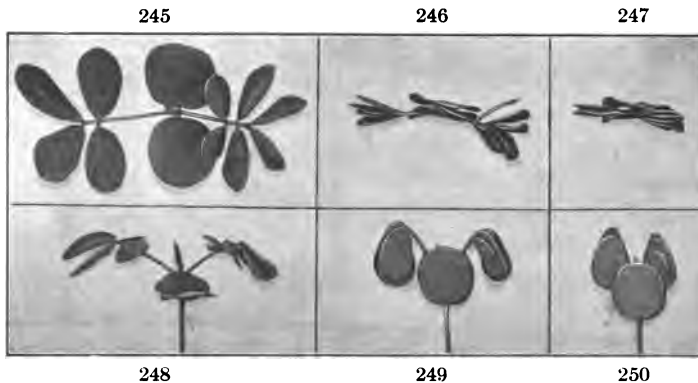
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FIGS. 242-244. — Showing the movements of *Amaranthus Palmeri*: 242, 243, position at sunrise and sunset (heliotropic) ; 244, night position (nyctitropic) half an hour after sunset. (From photographs by Prof. F. E. Lloyd.)

and even in the parts of the same compound leaf ; in the kidney bean, for instance, the common petiole turns up at night, while the individual leaflets turn down. One of the common pigweeds (*Amaranthus Palmeri*, Figs. 242-244) is heliotropic in the day time and nyctitropic at night.



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FIGS. 245-250. — Wild senna (*Cassia occidentalis*), showing the nyctitropic adjustments of its leaves. The upper figures show their horizontal arrangement ; those below, the vertical : 245, 248, position of the leaves at 9 A.M. ; 246, 249, at 3 P.M. ; 247, 250, at 6.30 P.M. (From photographs by Prof. F. E. Lloyd.)

The very striking nyctitropic adjustments of the wild senna (*Cassia occidentalis*) photographed by Professor Francis

E. Lloyd of the Alabama Polytechnic Institute (Figs. 245–250), though obviously influenced by the sun, are not directed toward it as in those of truly heliotropic plants.

These movements are common also among flowers, many of them having regular hours for opening and closing, as indicated by such names as “morning-glory” and “four-o’clock.” In these cases, however, other causes (277, 280) than the light relation must be taken into account.

201. Irritability is a general term applied to the power in plants of receiving and responding by spontaneous movements to impressions from without. In its widest acceptance, irritability includes, besides the various forms of adjustment described in this section and the next, all movements due to geotropism, those of roots seeking air and moisture, the revolution of twining stems and tendrils, the circulation of protoplasm in the cell — any movement, in short, that is made in response to an impression from the environment is a manifestation of irritability. It may be of various degrees, but is possessed to some extent by every living vegetable organism.

The term is usually applied, however, more especially to those obvious and pronounced responses made by plants to their surroundings, as exemplified in the cases just given. Still more marked instances are to be found in the movements of the tentacles of insectivorous plants, and the sensitive leaflets of the mimosa that close at the slightest touch. The tendrils of the passion flower are said to appreciate and respond to a pressure that cannot be distinguished even by the human tongue, and many plants will detect and respond to the ultra-violet rays of light, which are entirely invisible to man.

This faculty of irritability among plants corresponds, in an imperfect, rudimentary way, to what we recognize in animals as nervous excitability. By this it is not meant to imply that the two things are identical in their ultimate manifestations, though we may regard them as fundamentally the

same in that they are both to be referred to the property inherent in protoplasm of responding to stimuli. There is no indication, however, that irritability in the vegetable kingdom is accompanied by anything like consciousness or volition, or that plants possess any power of initiative. While the movements in response to stimuli are in many cases eminently adapted to a purpose, we have no evidence of a controlling power behind them. The movement comes automatically in response to the stimulus, whether the effect at the moment be advantageous or the reverse.

202. Adjustments in relation to moisture. — These adjustments may be — (1) To guard against excess of moisture; *e.g.* glands for excreting water and salts; scales, wax, down, etc., on the surface of leaves. These may serve also for protection against cold, insects, excess of light and heat. (2) For the conservation of moisture; *e.g.* the rev-

olute leaf margins of grasses and sand plants growing along the seashore; the fleshy leaves of stonecrops and purselanes; the hard epidermis of yuccas and aloes; the scales, scurf, and down, by which the moisture absorbed from the soil by plants

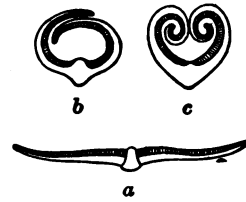


FIG. 251. — Cross sections of the leaf of sand grass: *a*, unrolled in its ordinary position; *b* and *c*, rolled up to prevent too rapid transpiration.

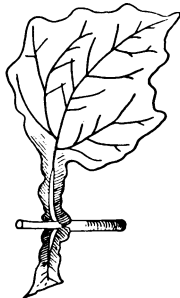


FIG. 252. — Winged petiole of *Polymnia*.



FIG. 253. — Water cups of *Silphium perfoliatum*.

growing in dry and barren places is prevented from escaping too rapidly through the stomata; the leaf cups and holders sometimes formed by winged petioles and clasping leaf bases for retaining dew or rain water.

(3) For leaf drainage, or the conduction of

moisture, by means of grooves, channels, and taper-pointed leaves, which act as natural gutters and drain pipes.

203. The fall of the leaf. — This is, in effect, an adjustment to change of temperature, but that it is not directly due to cold is shown by Exp. 75, and also by the fact that leaves in the tropics and those of evergreens, while they do not fall at stated periods like the bulk of the foliage in the temperate zones, are cut off just the same and replaced by new ones,



FIG. 254. — Fallen leaves. Notice how they cover the ground with a warm mulch, protecting the soil from denudation, and the roots and seeds from frost.

whenever, for any reason, they are unable to perform their function. In cold climates they fall at the approach of winter, not because the frost loosens them, but because the roots are not able to absorb enough moisture to supply them with material for making food. The needles and the scale-leaves characteristic of evergreens in cold regions are

enabled to persist indefinitely by reason of their contracted surface. This prevents the dissipation of moisture and affords no lodging for the accumulations of sleet and snow that would otherwise cumber and perhaps break the boughs with their weight. Trees and shrubs that shed their leaves in winter are said to be *deciduous*, from a Latin word meaning "to fall." Can you mention some advantages of the deciduous habit to a plant with broad, expanded leaves, growing in a cold climate?

The mechanical means by which the leaf fall is accom-

plished is through the growth of a corky layer of loose cells that forms at the base of the petiole and cuts it away from the stem, leaving a smooth, clean scar. Tear some fresh young leaves from a growing twig and compare the scars with those on a winter bough. Do you see any difference? This corky layer can be made to form in some plants artificially, by depriving them of working material. (Exp. 75.)

204. The protection of winter-green leaves. — A great many, perhaps the majority of broad-leaved evergreens, bear no obvious protection against cold, while a large proportion, such as chickweed, violet, fumitory, groundsel (*Senecio*), and dead nettle (*Lamium*), would seem peculiarly unfitted, by their delicate structure, to withstand it. But recent investigations by the Swedish botanist, Lidforss, have shown that all winter-green leaves, with the exception of those on submerged water plants, which are sufficiently protected by the medium in which they live, lose their starch in winter and contain instead an increased percentage of sugar. The same is true of other vegetable structures also, where starch is present, such as roots, stems, tubers, and winter fruits — nuts, haws, persimmons, and the like, which, as every schoolboy knows, become perceptibly sweeter after frost.

The presence of certain substances, of which sugar is the most frequent, enables plants to withstand a greater degree of cold than they could otherwise endure (Exp. 76). This effect, as shown by Lidforss's experiments, is due to the action of sugar in counteracting, or retarding, the "salting out" of proteins by cold, as explained in 33.

As sugar is readily reconverted into starch by exposure to a moderately high temperature for even a few days, we may find here an explanation of the fact that plants which have survived the prolonged cold of winter are often killed by a single sharp night frost following a few warm days in early spring, before the tender new growth has appeared. The

plant suffers, not from the direct effects of cold, but from the warmth preceding it, which stimulated the transformation into starch of the sugar that would have prevented the loss of proteins. On the same principle we may account for the puzzling fact that the sunny southern side of trees and shrubs usually suffers more from the effects of sudden frost than the shaded and colder northern face.

In apparent conflict with this reasoning is the fact that sugar cane and the sugar beet are peculiarly susceptible to cold. This, however, does not invalidate the premises established by Lidforss's researches, but merely emphasizes the need of further investigation, which may either reconcile all the facts, or modify their interpretation.

205. The colors of autumn leaves. — These are due to the breaking up and disappearance of the chlorophyll when the leaf factory has to "shut down" for want of raw material to work with (203). It is closely connected with the appearance of frost, since the same changes of temperature which produce frost cause the cessation of sap flow that brings about the disorganization of the chlorophyll and the formation of various pigments derived from it. Besides these, leaves may contain other coloring matters that are perceptible only when the chlorophyll disappears; and in the sap there is a reddish pigment which becomes either a very bright red, or a dark purplish maroon, from the effect of chemicals that combine with it in the leaves. With these coloring materials at command it is easy to see how the autumn woods can assume such splendid hues.

Practical Questions

1. How would you explain the fact that the outer twigs of trees generally are the most leafy? (99, 194; Exps. 57, 74.)
2. Is the common sunflower a compass plant? Is cotton?
3. Are there any such plants in your neighborhood?
4. Compare the leaves of half a dozen shade-loving plants of your neighborhood with those of as many sun-loving ones; which, as a general thing, are the larger and less incised?

5. Give a reason for the difference. (169.)
6. Why do most leaves — notably grasses — curl their edges backward in withering? (182.)
7. What advantage is gained by doing this? (202.)
8. Observe such of the following plants as are found in your neighborhood, and report any changes of position that may take place in their leaves and the causes to which such changes should be ascribed: wood sorrel, mimosa, honey locust, wild senna, partridge pea, wild sensitive plant, redbud, bush clover, Japan clover, Kentucky coffee tree, sensitive brier (*Schrankia*), peanut, kidney bean.
9. Which of the trees named below shed their leaves from base to tip of the bough (centripetally), and which in the reverse order: ash, beech, hazel, hornbeam, lime, willow, poplar, pear, peach, sweet gum, elm, sycamore, mulberry, China tree, sumac, chinquapin?
10. Account for the fact that evergreen trees and shrubs have generally thick, hard, and shiny leaves, like those of the holly and magnolia, or scales and needles, as the cedar and pine. (203.)
11. Why do many plants which are deciduous at the North tend to become evergreen at the South? (203.)
12. Why are evergreens more abundant in cold than in warm climates? (203.)
13. There is an apparent inconsistency between questions 11 and 12; can you reconcile it? (203.)
14. Why is it more important to protect the south side of trees against exposure to frost than the northern side? (33, 204.)
15. Explain why peach orchards on the tops and northern slopes of elevated areas are less liable to have their fruit destroyed by late frost than those in the valleys and on the southern slopes. (33, 204.)

VIII. MODIFIED LEAVES

MATERIAL. — Get from a florist a potted plant of sundew, Venus's-flytrap, *sarracenia*, or, if possible, one of all three, and keep in the school-room for observation. The subject can be studied best in a well-stocked greenhouse, if one is accessible.

206. Modification and adaptation. — Modification is structural adjustment, or adaptation, carried so far as to obscure the original form of an organ. Its true nature, however, can generally be determined by some of the tests mentioned in 100.

Examples of the modification of leaves to do the work of

other organs have already been noticed, as also their entire disappearance in certain cases (97, 101, 149) and replacement by other parts; it is unnecessary, therefore, to revert to this branch of the subject here.



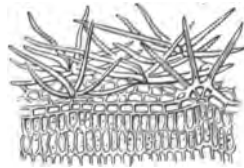
FIG. 255.—Spearlike leaves of Spanish bayonet.

207. Protective modifications.—The most general protective modifications that leaves undergo are (1) for the conservation of moisture, as explained in 202, and (2) for protection against animals. Many of the adaptations for the former purpose serve incidentally for defense against animals also. Spines, hairs, scales, sticky exudations, water holders, clasping and

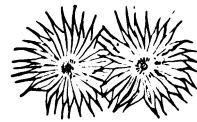
perfoliate leaves bar the way to crawling insects; horny cuticles, as well as offensive odors, bitter secretions, and



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FIGS. 256-258.—Protective hairs magnified: 256, mullein; 257, cinque-foil; 258, Shepherdia.

poisonous juices warn leaf-eating cattle and bugs away. These devices are merely protective, however, and adapted to a passive attitude of self-defense.

208. Insectivorous leaves.—But sometimes a plant

becomes the aggressor, and instead of standing on the defensive or suffering itself to be quietly devoured, proceeds to capture and devour small game on its own account, and in this case, the leaf sometimes becomes a deadly weapon of destruction.

209. Pitcher plants.—The *sarracenia*, or trumpet leaf, is a familiar example of this class. The lower part of the leaf blade is transformed into a hollow vessel for holding water, and the top is rounded into a broad flap called the *lamina*. Sometimes the lamina stands erect, as in the common yellow trumpets of our coast regions, and when this is the case, it is brilliantly colored and attracts insects (Fig. 259). Sometimes, as in the parrot-beaked and the spotted trumpet leaf, it is bent over the top of the water vessel like a lid, and the back of the leaf, near the foot of the lamina, is dotted with transparent specks that serve to decoy foolish flies away from the true opening and tempt them to wear themselves out in futile efforts to escape, as we often see them do against a window pane.



FIG. 259. — Yellow trumpets (*Sarracenia flara*).
(From the Mo. Botanical Garden Rep't.)

If the contents of one of these leaves are examined with a lens, there will generally be found mixed with the water at the bottom the remains of the bodies of a large number of insects. The hairs on the outside all point up, toward the rim of the pitcher, while those on the inside turn down, thus smoothing the way to destruction, but making return

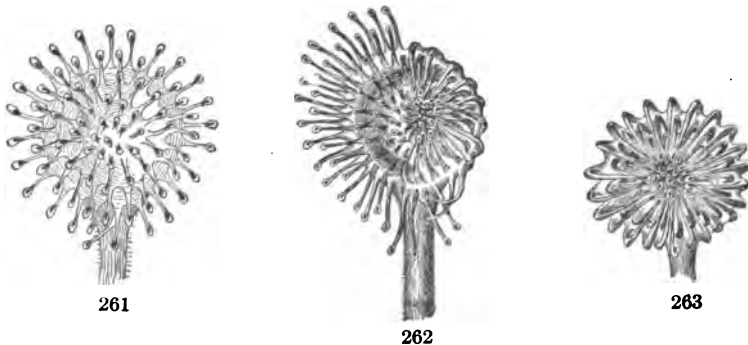
impossible to a small insect when once it is ensnared. When we remember that these plants are generally found in poor, barren soil, we can appreciate the value to them of the animal diet thus obtained.



FIG. 260. — Plant of sundew.

210. Flytraps. — The most remarkable examples of insect-catching leaves are the Venus's-flytrap, found in the seacoast region of North Carolina, and the sundew (*Drosera rotundifolia*), common on the margins of sandy bogs and ponds. The latter is a delicate, innocent-looking little plant, and owes its poetic name to the dewlike appearance of a shining, sticky

fluid exuded from glands on its leaves, which glitter in the sun like dewdrops. It is, however, a most voracious carnivorous plant, the sticky leaves acting as so many bits of fly paper by means of which it catches its



FIGS. 261-263. — Leaves of sundew magnified: 261, leaf expanded; 262, leaf closing over captured insect; 263, leaf digesting a meal.

prey. When a fly has been trapped, the tentacles close upon it, the edges of the leaf curve inward, making a sort of stomach, from the glands of which an acid juice exudes and

digests the meal. After a number of days, varying according to the digestibility of the diet, the blades slowly unfold again and are ready for another capture.

The bladderwort, common in pools and still waters nearly everywhere, has its petioles transformed into floats, while

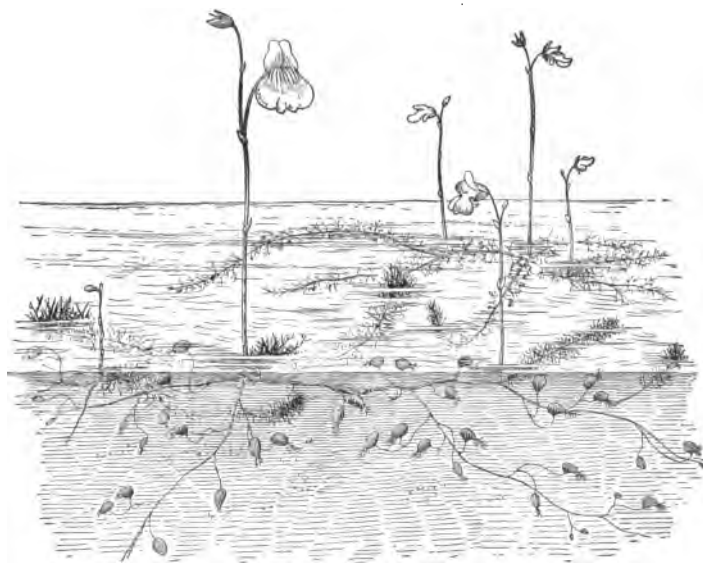


FIG. 264. — Bladderwort, showing finely dissected submerged leaves bearing bladders for capturing animalculæ.

the finely dissected, rootlike blades bear little bladders which, when examined under the microscope, are found to contain the decomposed remains of captured animalculæ.

Practical Questions

1. Can you find any kind of leaf that is not preyed upon by something? If so, how do you account for its immunity?
2. Make a list of some of the most striking of the protected leaves of your neighborhood.
3. What is the nature of the protective organ in each case?
4. For protection against what does it seem to be specially adapted?
5. Are the plants in your list for the most part useful ones, or troublesome weeds?

6. Examine the leaves of the worst weeds that you know of and see if these will help in any way to account for their persistency.

Field Work

(1) In connection with Sections I and II, observe the effect of the lobing and branching of leaves in letting the sunlight through. Notice any general differences that may appear as to shape, margin, and texture in the leaves of sun plants, shade plants, and water plants, and account for them. Study the arrangement of leaves on stems of various kinds, with reference to the size and shapes of leaves and their light relations. Consider the value of the various kinds of foliage for shade; for ornament; as producers of moisture; as food; as insect destroyers, etc.

Make a special study of the twelve principal deciduous trees of your neighborhood. Compare the leaves, bark, and branches of the same trees so that you will be able to recognize them by any one of these means alone.

(2) In connection with Sections III and V, consider the effects upon soil moisture of transpiration from the leaves of forest trees and from those of shallow-rooted herbs and weeds that draw their water supply from the surface. Consider the value of forests in protecting crops from excessive evaporation by acting as wind breaks. Study the effect of the fall of leaves upon the formation of soil. In any undisturbed forest tract turn up a few inches of soil with a garden trowel and see what it is composed of. Notice what kind of plants grow in it. Note the absence of weeds and account for it. Compare the appearance of trees scattered along windy hillsides, where the fallen leaves are constantly blown away, or in any position where the soil is unrenewed, with those in an undisturbed forest, and then give an opinion as to the wisdom of hauling away the leaves every year from a timber lot.

(3) In Section VII, observe, in different kinds of leaf mosaics, the means by which the adjustment has been brought about and the purpose it subserves. Make a list of plants illustrating the two habits. Notice the form and position of petioles of different leaves, and their effect upon light exposure, drainage, etc., and the behavior of the different kinds in the wind. Look for compass plants in your neighborhood, and for other examples of adjustment to heat and light. Study the position of leaves at different times of day and in different kinds of weather and note what changes occur and to what they are due.

Make a list of ten plants that seem to you to have best worked out the problem of leaf adjustment, giving the reasons for your opinion.

Study the drainage system of different plants and observe whether there is any general correspondence between the leaf drainage and the root sys-

tems. This will lead to interesting questions in regard to irrigation and manuring. Where plants are crowded, the growth of both roots and leaves is complicated with so many other factors that it is best to select for observations of this sort specimens growing in more or less isolated situations.

Notice the time of the expansion and shedding of the leaves of different plants, and whether the early leafers, as a general thing, shed early or late; in other words, whether there seems to be any general time relation between the two acts of leaf expansion and leaf fall.

(4) Under Section VIII, look for instances of modified leaves; study the nature of the different modifications you find, and try to understand their meaning and object. Make a collection (*a*) of all the leaves you can find modified to serve other than their normal purposes; (*b*) of all the organs of other kinds that have been modified to serve as leaves; (*c*) of all the modified parts of leaves — stipules and petioles — that you can find. Keep the collections separate, labeling each specimen with the name of the plant it belongs to, what part it is, what use it serves, when and where found. These collections need not be made individually, but by the class as a whole and kept for the use of the school.

Observe also (*d*) the differences between young and old leaves of the same kind, and the leaves of young and old plants or parts of plants of the same kind; (*e*) resemblances between young leaves belonging to plants of different species; (*f*) between young leaves of one species and mature ones of one or more different species. Make a collection of all the specimens you can find illustrating the three points mentioned, referring each to its proper head, and giving the name and relative age — old or young — of all specimens collected.

CHAPTER VII. THE FLOWER

I. DISSECTION OF TYPES WITH SUPERIOR OVARY

MATERIAL. — For monocotyls, any flower of the lily family, such as tulip, dogtooth violet (*Erythronium*), trillium, star-of-Bethlehem, yucca, bear's grass, and the like. The large garden lilies make particularly good examples, but they are for the most part spring bloomers. For autumn, spiderwort (*Tradescantia*), arrow grass (*Sagittaria*), or late specimens of colchicum and tiger lily may be used. Any of these will meet the essential conditions of the analysis given in the text, but care should be taken not to select for this exercise lily-like flowers of the iris and amaryllis families, which have the *ovary inferior*.

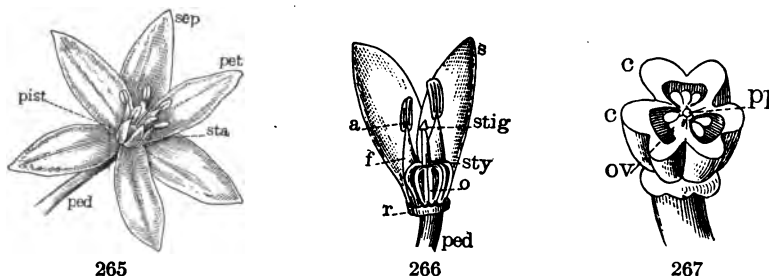
For examples of hypogynous dicotyls, flax, linden, pinks, corn cockle, wood sorrel, poppies, tomato blossoms, and other common flowers can usually be obtained without difficulty. In autumn, the geraniums so largely cultivated for ornament will meet all the conditions of the analysis. Specimens of the cress family — wallflower, cabbage, mustard, turnip — can generally be found everywhere and at all seasons, and they possess the advantage of having their flowers throughout the order put up on so nearly the same pattern that a description of one species will answer, even in details, for the rest.

For sympetalous specimens of the hypogynous type, hyacinth, lily of the valley, bearberry, huckleberry, or other equivalent forms may be used.

APPLIANCES. — A compound microscope may be needed for examining minute objects, such as pollen grains and ovules; but for all other purposes, a good hand lens, with the pupil's ordinary laboratory equipment of drawing-materials, notebook, and dissecting needles, will be sufficient for the studies outlined in this and the four succeeding sections.

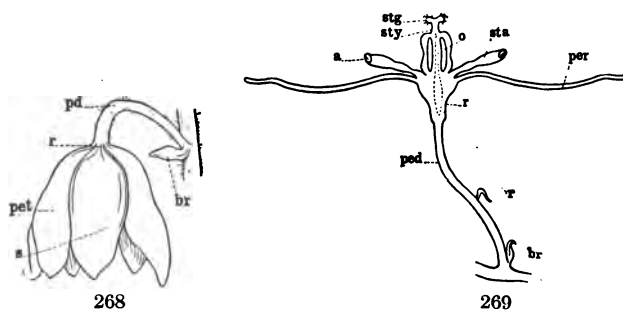
211. The floral envelopes. — Make a sketch of your specimen flower from the outside. Is it solitary, or one of a cluster? If the latter, refer to 160–162 and tell the nature of the cluster. Notice the color; is it conspicuous enough to attract attention or not? Can this have anything to do with its clustered or solitary position? Label the head of the peduncle that supports the flower, *receptacle*; the outer

greenish leaves, *sepals*; the inner, lighter-colored ones, *petals*. The sepals taken together form the *calyx*, and the petals, the *corolla*. Where the petals and sepals are all



FIGS. 265-267.—Flower of a monocotyl (star-of-Bethlehem), with superior ovary dissected: 265, entire flower, showing the different sets of organs: *pet*, petals; *sep*, sepals; *sta*, stamens; *pist*, pistil; *ped*, peduncle; 266, side view with all the petals and sepals but two removed to show order of the parts: *r*, receptacle; *o*, ovary; *sty*, style; *stig*, stigma—parts composing the pistil; *f*, filament; *a*, anther—parts composing the stamen; 267, cross section of the ovary: *c*, carpels; *ov*, ovules; *pl*, placenta.

separate and distinct, as in the tulip and the star-of-Bethlehem, the corolla is said to be *polypetalous* and the calyx *polysepalous*, words meaning, respectively, many-petaled and many-sepaled. *Monopetalous* and *monosepalous*, or

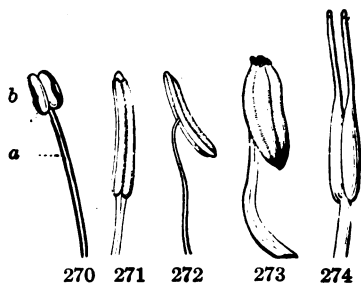


FIGS. 268-269.—Yucca blossom: 268, external view: *br*, bract; *pd*, peduncle; *r*, receptacle; *s*, sepal; *pet*, petal; 269, vertical section: *ped*, peduncle; *br*, bract; *r*, receptacle; *per*, perianth; *sta*, stamen; *o*, ovary; *sty*, style; *stig*, stigma. The last three parts named compose the pistil.

sympetalous and *synsepalous*, are terms used to describe a condition in which the petals or sepals are all united into one, as in the morning-glory and lily of the valley. In many

flowers, there is little or no difference between the two sets of organs. In such cases the calyx and corolla together are called the *perianth*, but the distinction of parts is always observed, the outer divisions being regarded as sepals, the inner ones as petals. These two sets of organs constitute the *floral envelopes*, and are not essential parts of the flower, as it can fulfill its office of producing fruit and seed without them. Note their number, mode of attachment to the receptacle, and how they alternate with each other. Remove one of the sepals and one of the petals, and notice any differences between them as to size, shape, or color. Which is most like a foliage leaf? Hold each up to the light and try to make out the veining. Is it the same as that of the foliage leaves? If a light-colored flower is used, examine a specimen that has stood in coloring fluid. How many of each set are there?

212. The essential organs. — Next sketch the flower on its inner face, labeling the appendages just within the petals,



FIGS. 270-274. — Stamens: 270, a typical stamen with the terminal anther, *b*, surmounting the filament, *a*, and opening in the normal manner down the outer side of each cell; 271, stamen of tulip tree, with adnate exserted anther; 272, stamen of an evening primrose (*Enothera*) with versatile anther; 273, stamen of pyrola, the anther cells opening by chinks or pores at the top; 274, stamen of a cranberry, with the anther cells prolonged into a tube and opening by a pore at the apex. (After GRAY.)

stamens, and the central organ within the ring of stamens, *pistil*. These are called *essential organs* because they are necessary to the production of fruit and seed. Note their mode of insertion, three of the stamens in a flower like the star-of-Bethlehem alternating with the petals, and the other three with these and with the lobes of the base of the pistil.

213. The stamens. — Notice whether the stamens are all alike, or whether there are differences as to size, height, shape, color, etc. Do these differences, if there are any,

occur indiscriminately and without order, or in regular succession between the alternating stamens? Examine one of the little powdery yellow bodies at the tip of the stamens, and see whether they face toward the pistil or away from it.

Remove one of the stamens and sketch as it appears under the lens; labeling the powdery yellow body at the top, *anther*, and the stalklike body supporting it, *filament*. Usually the filaments are threadlike, whence their name, but sometimes, as in the star-of-Bethlehem, they are flattened and look like altered petals. See if you can find such a one. What would you infer from this fact as to the possible origin of the stamens? (100.)

Notice the two little sacs or pouches that compose the anther, as to their shape and manner of opening, or dehiscing, to discharge the powder contained in them. This powder is called *pollen*, and will be seen under the lens to consist of little yellow grains. These are of different shapes, colors, and sizes, in different plants, and their surface often appears beautifully grooved and striate when sufficiently magnified. Place some of the pollen under the microscope and draw two of the grains, with their markings. In the hibiscus and others of the mallow family, they are large enough to be seen with a hand lens.



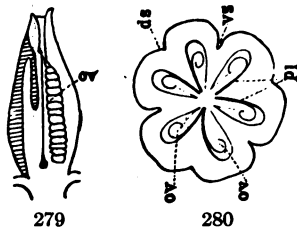
FIGS. 275-278. — Forms of pollen: 275, from *mimulus*; 276, star cucumber; 277, wild balsam apple; 278, *hibiscus*. (After GRAY.)

214. The pistil. — Remove the stamens and sketch the pistil as it stands on the receptacle. Label the round or oval enlargement at the base, *ovary*, the threadlike appendage rising from its center, *style*, and the tip end of the style, *stigma*. In some specimens the style may be very short, or wanting. In this case the stigma is *sessile*, and the pistil consists of stigma and ovary alone. If the stigma is lobed or parted, count the divisions and see if there is any correspondence between them and the number of petals and sepals,

or of the lobes of the ovary. Examine the tip with a lens and notice the sticky, mucilaginous exudation that moistens it. Can you think of any use for this? If not, touch one of the powdery anthers to it, and examine it again with a lens. What do you see? Can you blow or dust the pollen from the stigma?

215. Pollination, or the transfer of pollen from the anther to the stigma, is a matter of great importance, as the pistil cannot develop seed without it, except in the case of a few plants like the Alpine everlasting, some species of meadow rue (*Thalictrum*), and *Alchemilla*, which have the unusual faculty of perfecting seeds in the absence of pollen. Note the relative position of pistils and stamens and see if it is such that the pollen can reach the stigma without external agency.

216. The ovary. — Observe the shape of the ovary, and the number of ridges, or grooves, that divide the surface.

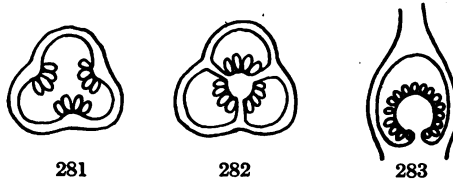


FIGS. 279, 280. — Ovary of *yucca*, a hypogynous monocotyl, dissected: 279, vertical section; *ov*, ovules; 280, diagram of a horizontal section of the same, enlarged, showing the three carpels and six locules; *ds*, dorsal sutures; *vs*, ventral sutures; *ov*, ovules; *pl*, placenta.

Select a flower which has begun to wither, so that the ovary is well developed, cut a cross section near the middle, and try to make out the number of *locules*, or internal divisions. Do you perceive any correspondence in number between these and the ridges or lobes outside (Fig. 280)? Between them and the lobes of the stigma? The walls that inclose the cavities of the ovary are called *carpels*, and the ridges or depressions that mark their point of union on the outside are the *sutures*, or seams. The little round

bodies in the locules, as the compartments of the ovary are called, are the *ovules*, which will later be developed into seeds. Their place of attachment is the *placenta*. If they are attached to the walls of the carpels (Fig. 281), the placenta

is *parietal*; if to a central axis formed by the edges of the carpels projecting inwards (Fig. 282), it is central and axial; if instead of being attached to the carpels, the ovules are borne on a projection from the receptacle, the placenta is a *free central* one (Fig. 283). If your cross section shows a central placenta, make a vertical cut down to the receptacle and find out whether it is free, or axial. What appears to be the primary office of the ovary? Make an enlarged sketch of your specimen in both vertical and horizontal section, labeling correctly all the parts observed.



FIGS. 281-283. — Different kinds of placenta : 281, parietal; 282, central and axial; 283, free central. 281 and 282 are horizontal sections; 283, vertical.

217. Numerical plan. — Make a horizontal diagram of the plan of the whole flower, after the model given in Fig. 284, showing the order of attachment of the different cycles, — sepals, petals, stamens, and pistils, — the number of organs in each set, and their mode of alternation with the organs of the other cycles. Notice that the



FIG. 284. — Horizontal diagram of a flower of the lily kind. The dot represents the growing axis of the plant.

parts of each set are in threes, or multiples of three. This is called the numerical plan of the flower, and is the prevailing number among monocotyls. It is expressed in botanical language by saying that the flower is *trimerous*, a word meaning measured, or divided off, into parts of three.

218. Vertical order. — Next make a vertical diagram of your specimen after the manner shown in Fig. 269, and note carefully that the ovary stands *above* the other organs (this is true of all the lily family), and is entirely separate and distinct from them. In such cases the ovary is said to be *free*, or *superior*, and the other organs *inferior*, or *hypogynous*, a word meaning “in-

serted under the pistil." These terms should be remembered, as the distinction is an important one in plant evolution.

219. Summary of observations. — In the flower just examined, we found that there were four sets of floral organs present — sepals, petals, stamens, and pistil; that the individual organs in each set were alike in size and shape; that there were the same number, or multiples of the same number of parts in each set, and that all the parts of each set were entirely separate and disconnected, the one from the other, and from those of the other cycles. Such a flower is said to be: —

Perfect, that is, provided with both kinds of organs essential to the production of seed — stamens and pistil.

Complete, having all the kinds of organs that a flower can have: viz. two sets of essential organs, and two sets of floral envelopes.

Symmetrical, having the same number of organs, or multiples of the same number, in each set.

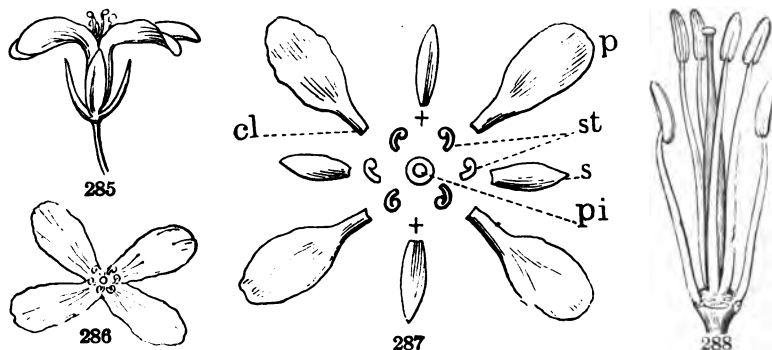
Regular, having all the parts of each set of the same size and shape, as in the wild rose and bellflower, or if different, arranged in regular order or pairs, so that there will be a correspondence between the two sides of the flower, as in the violet, sweet pea, sage, and larkspur. For convenience, the two kinds may be distinguished as *complete* and *bilateral regularity*, respectively.

The opposites of these terms are: *imperfect*, *incomplete*, *asymmetrical* or *unsymmetrical*, and *irregular*.

Note that regularity refers to form, symmetry to number of parts, and that a flower may be perfect without being complete.

220. Dissection of a typical dicotyl flower. — (Poppy, flax, pink, tomato, linden, etc., can be substituted for the specimen used in the text.) Gently remove the sepals and petals from a wallflower, stock, mustard, or other cress flower, lay them on the table before you in exactly the order in which they grew on the stem, and sketch them. How

many of each are there, and how do they alternate with one another? Sketch the pistil and stamens as they stand on



FIGS. 285-288. — A flower of the cross family: 285, side view; 286, view from above; 287, diagram of parts: *p*, petals; *s*, sepals; *st*, stamens; *pi*, pistil; *cl*, claw of petal; +, +, position of the missing stamens; 288, pistil and stamens, enlarged. (After GRAY.)

the receptacle; how many of the latter are there? Notice that two of the six are outside and a little below the others, alternate with the petals, while the other four stand opposite them, as is natural, if they were alternating with another ring of stamens between themselves and the corolla. Put a dot before two of the sepals in your first drawing to indicate the position of the two outer stamens, and a cross before the other two to show where stamens are wanting to complete the symmetry of this set, as in Fig. 287. When parts necessary to complete the plan of a flower are wanting, as in this case, they are said to be *obsolete*, *suppressed*, or *aborted*. Place dots before the petals to represent the other four stamens. Sketch one of the anthers as it appears under a lens, showing the arrow-shaped base, and the mode of attachment to the filament. Is it such that the pollen can reach the stigma without external agency? In what manner do the anthers open to discharge their pollen? Are the anthers and stigma mature at the same time? Remove all the stamens from a flower and sketch the pistil, showing the long, slender ovary, the very short style, and the

capitate (that is, round and knoblike) stigma. Make cross and vertical sections of one of the older pistils lower down

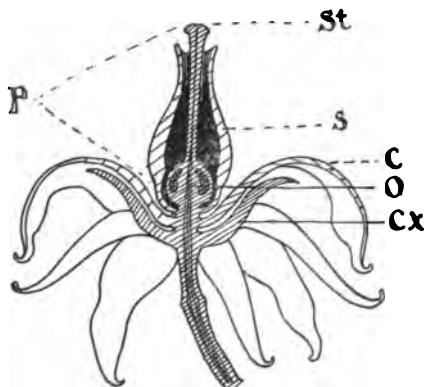


FIG. 289. — Section of a tomato flower, showing the hypogynous arrangement: *cx*, calyx; *c*, corolla; *s*, stamens; *p*, pistil; *o*, ovary, *st*, stigma. (Twice natural size.)

on the stem. How many ovules does it contain? How are they attached? Represent the position of the pistil by a small circle in the center of your sketch of the separate parts. You have now a complete ground plan of the flower. Diagram a vertical section, as in Fig. 289, showing the position of the ovary with reference to the other parts, and report

in your notebook as to the following points: —

Numerical plan	Presence or absence of parts
Symmetry	Union of parts
Regularity (complete or bilateral)	Position of ovary

II. DISSECTION OF TYPES WITH INFERIOR OVARY

MATERIAL. — For monocotyls: in spring and early summer, iris, snowflake, freesia, crocus, narcissus, daffodil, can be used; in autumn, gladiolus, blackberry lily, fall crocus, star grass (*Hypoxys*). For dicotyls: in spring, flowers of apple, pear, quince, gooseberry, squash, gourd, melon (with both male and female flowers); in late summer and autumn, fuchsia, evening primrose (*Oenothera*), willow-herb (*Epilobium*).

221. Study of a monocotyl flower. — Compare with the specimens examined in the last section, a narcissus, snowflake, or iris flower. What difference do you notice in the position of the ovary? Would you call it *inferior* (below the other parts) or *superior* (above them)? How was it in the lily and the hyacinth? If your specimen is an iris, notice that it is sessile in the axil of a large bract called a *spathe*,

which conceals the lower part of the flower. Remove the spathe and observe that the lower part of the perianth is united into a long, narrow tube, from the top of which the sepals and petals extend as long, curving lobes.



FIG. 290.—Iris flower: *sp*, spathes; *s*, sepals + *p*, petals = perianth.

222. Arrangement of parts. —

Sketch the outside of the flower, labeling the oblong, three-lobed enlargement at the base, *ovary*; the prolongation above it, *tube of the perianth*; the three outer lobes with the broad sessile bases, *sepals*; the others, with their bases

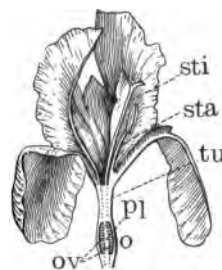


FIG. 291.—Vertical section of iris flower: *ov*, ovules; *pl*, placenta; *tu*, tube of the perianth inclosing the style; *sta*, stamen; *sti*, stigma; *o*, ovary. (After GRAY.)

narrowed and bent inward, *petals*. Now turn the flower over and sketch the inside, labeling the three large, petal-like expansions in the center, *stigmas*. Do you see any stamens? Remove one of the sepals and look under the stigma; what do you find there? Notice the little honey pockets at the foot of the stamen. Run the

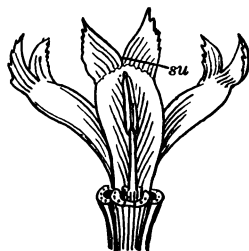


FIG. 292.—Vertical section of iris flower, with perianth removed, showing a stamen and three stigmas: *su*, stigmatic surface.

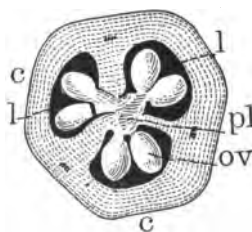


FIG. 293.—Cross section of ovary of iris flower: *c*, *c*, carpels; *l*, *l*, locules; *ov*, ovules; *pl*, placenta.

head of your pencil into them and see what would happen to the head of an insect probing for honey.

Remove the perianth and sketch the remaining organs in profile, showing the position of the stamens. Do you see any advantage in their position? Can you determine the use of the crest of hairlike filaments on the upper side of the sepals? Remove a stamen and sketch it.

223. The pistil. — Remove as much of the upper part of the perianth tube as you can without injuring the pistil, and with a sharp knife cut a vertical section down through the ovary so as to show the long style and its connection with the placenta. Make a sketch of this longitudinal section (see Fig. 291), labeling the parts observed. Notice whether the placenta is central or parietal. Draw a cross section of the ovary; how many locules has it? How many ovules in each? Where are they attached? Is the placenta free central or axial (Fig. 293)? Examine with a lens the little flap at the base of the two-cleft apex of one of the stigmas, and look for a moist spot to which the pollen will adhere. Label this in your sketch, *stigmatic surface*. No seeds can be matured unless some of the pollen reaches this surface; can you think by what agency it is carried there? What insects have you seen hovering about the iris? Notice that in drawing his head *out* of the flower, an insect would not touch the stigmatic surface, since it is on the *upper* side of the flap and he would be probing *under* it. But in entering the next flower that he visits, he is likely to strike his head against the flap and turn it under, thus dusting it with pollen brought from another flower.



FIG. 294. — Horizontal diagram of iris flower.

224. Diagrams. — Draw diagrams showing the horizontal and vertical arrangement of parts in the iris or other specimen examined, and compare with those made of the monocotyl studied in the preceding section. In what respect does it differ from them? How do you account for the difference in the number of stamens, if there is any? (220.)

225. The vertical order. — The difference in vertical arrangement is an important one. Bear in mind that flowers of this type have the ovary *inferior*, that is, inserted *under* the other organs (Figs. 296, 304), which are then said to be superior, or *epigynous*, a word which, as you know from the prefix *epi* (47), means over or above the pistil. To make the matter clear, the two sets of terms employed for describing the position of the ovary are given below in parallel columns:

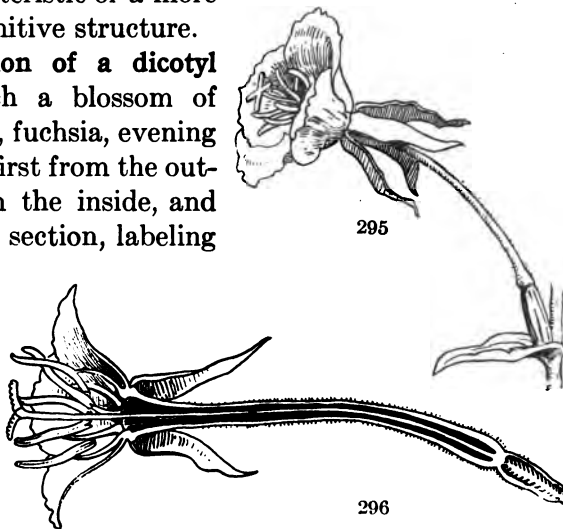
Hypogynous	Epigynous
Ovary superior	Ovary inferior
Calyx or perianth inferior	Calyx or perianth superior

The epigynous arrangement is considered as marking a higher stage of floral development than the hypogynous, which is characteristic of a more simple and primitive structure.

226. Dissection of a dicotyl flower. — Sketch a blossom of quince or apple, fuchsia, evening primrose, etc., first from the outside, then from the inside, and then in vertical section, labeling the parts as in your other sketches. Notice in the pear or apple how the ovary is sunk in the hollowed-out receptacle.

Where are the other parts

attached? Are they inferior or superior? Hold up a petal to the light and examine its venation through a lens. (Use for this purpose a petal from a flower that has stood in red ink for two or three hours.) Is it parallel-veined or net-



FIGS. 295-296. — Evening primrose, dicotyl flower with inferior ovary: 295, exterior view; 296, longitudinal section, showing vertical arrangement of parts.

veined? If the flowers are clustered, what is the order of inflorescence? Does the position of the flowers on their

branch correspond to that of the leaf axils on the same kind of plant?



FIGS. 297-300. — Flower and sections of pear: 297, cluster of blossoms, showing inflorescence; 298, vertical section of a flower; 299, ground plan of a flower; 300, vertical section of fruit.

227. The stamens. — Remove the petals from a flower and examine the stamens with a lens. Notice the attachment and shape of the anthers. Are they all of the same color? How do you account for the difference, if there is any? Is the position of the pistil and stamens such that the pollen from the anthers can readily reach the stigmas without external aid? Examine the pistil in flowers of different ages, and

see if the stigma is mature (that is, moist and sticky) at the same time that the anthers are discharging their pollen. Make an enlarged sketch of a stamen showing the shape of the anther and the method of opening to discharge pollen.

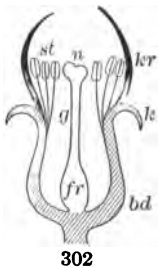
228. The pistils. — How many pistils do you find in the apple blossom (or other flower under examination)? Are they distinct, or united? Find where the styles originate; what do you see there? Make a cross section of the ovary and count the locules; how does their number compare with that of the styles? Can you make out the number of ovules in each? If not, use a young fruit; as it is only an enlarged ovary, it will show the parts correctly. Compare it with a ripe fruit and see if all the ovules matured. Can you think of any reasons why some of them might fail? Do you see any signs of nourishment stored in the ovary? Name all the ways you can think of in which the ovary can benefit the

ovules and seeds. Draw the ovary in cross and vertical sections, labeling correctly all the parts.

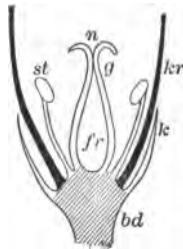
229. The numerical plan of dicotyls. — Diagram the plan of the flower in cross and vertical section. How many parts are there in each set? Can you tell readily the number of stamens? When the individuals of any set or cycle of organs are too numerous to be easily counted, like the stamens of the apple, pear, and peach, or the petals of the water lily, they are said to be *indefinite*. It is very seldom that perfect symmetry is found in all parts of the flower. The stamens and pistil, in particular, show a great tendency to variation, so that the numerical plan is generally determined by the calyx and corolla. Where the parts are in fives, as in the pear, quince, and wild rose, the flower is said to be *pentamerous*, or in sets of five. This is the prevailing number among dicotyls, though other orders are



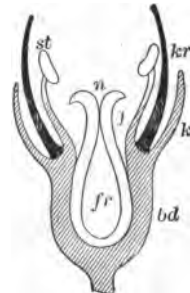
FIG. 301. — Vertical section of an almond blossom with petals removed, showing the perigynous arrangement.



302



303



304

FIGS. 302-304. — Diagrams showing arrangement of parts with reference to the ovary: *bd*, receptacle; *k*, calyx; *kr*, corolla; *st*, stamens; *fr*, ovary; *g*, style; *n*, stigma; 302, perigynous; 303, hypogynous; 304, epigynous.

not uncommon. In the mustard family (220) and other well-known species, the fourfold order prevails, while some of the saxifrages have their parts in twos, and the magnolia and the pawpaw have a threefold arrangement.

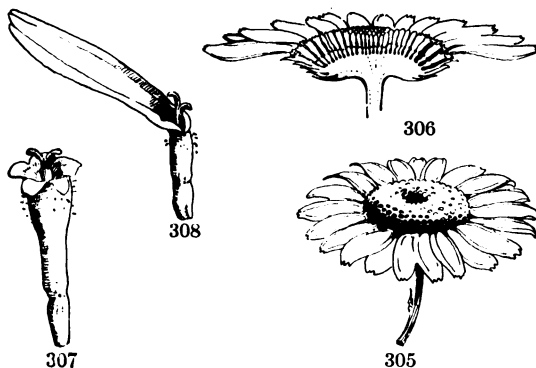
230. Intermediate types. — Flowers like the peach and rose represent an intermediate type in which the calyx, petals, and stamens are attached to a prolongation of the receptacle that extends above the ovary, but is not united with it (Fig. 301). In general, a flower is not considered as belonging to the epigynous kind unless the ovary is more or less consolidated with the parts around it (Fig. 304).

III. STUDY OF A COMPOSITE FLOWER

MATERIAL. — The largest heads attainable should be selected, as the florets are small at best, and difficult to handle. The large cultivated sunflower (*Helianthus annuus*) makes an ideal specimen, if accessible. Oxeye daisy and dandelion can be obtained throughout the season almost everywhere, but the former has no pappus, and the latter does not show the tubular disk flowers. Other common specimens are : for spring, mayweed, Jerusalem artichoke, coreopsis, arnica ; for late summer and autumn, China aster, golden aster (*Chrysopsis*), sneezeweed, elecampane — and, in fact, the great majority of flowers to be found at this season are of the composite family. Oxeye daisy is used as a model in the text on account of its general accessibility, but almost any specimen of the radiate kind will meet all essential conditions of the analysis.

231. The ray flowers. — Examine the upper side of an oxeye daisy through a lens. Of what is the yellow button in the center composed? Count the narrow, petal-like rays dis-

posed around the center. To decide what they are, look for a small two-cleft body at the base of the ray ; this is the pistil. Do you see any stamens in the ray? An examination will show that all the rays



FIGS. 305-308. — An oxeye daisy : 305, a flower head ; 306, vertical section of a head ; 307, disk flower ; 308, ray flower, enlarged.

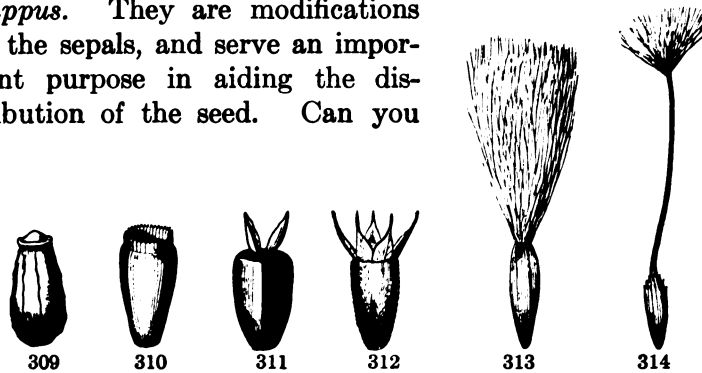
contain pistils, but no stamens ; they are, therefore, not petals, but the corollas of imperfect flowers. Look at the upper edge of a ray of sneezeweed, coreopsis, arnica, chicory, etc., for small teeth or notches ; these represent the lobes of a sympetalous corolla. Split one of the tubular corollas of the disk down one side and open it out flat ; does it throw any light on the morphology of the ray ? In many composite plants, as the sunflower, coneflower, coreopsis, the rays are all *neutral* ; that is, they have neither pistil nor stamens. Are they of any use in such cases ? If you are in doubt, remove all the rays from a head ; would the disk be noticeable enough to attract attention without them ? What is the principal office of the rays ?

232. The involucre. — Look at the cluster of green, leafy scales on the under side of the head. It is not a calyx, but a collection of bracts, called an *involucre*. Have you ever noticed the bracts under the separate flowers on a raceme ? (151.) What would be the position of the bracts if all the flowers of the raceme were compacted into a head like the daisy or sunflower ? Is the involucre of any use ? Cut it away gently so as not to disturb the other organs and see what happens to the rays.

233. The disk flowers. — Cut a vertical section through the head of a flower and notice the broad, flat receptacle (in some cases round or columnar) on which the tiny florets are seated. Observe whether it is naked, or whether it bears chaffy scales inclosing the florets. Make an enlarged drawing of this section, showing the insertion of the different parts and labeling them all correctly. What differences do you observe between the disk and the ray flowers ?

234. The pappus. — Open one of the disk flowers with a dissecting needle and observe the small striate (in some specimens, hairy) body to which the base of the style is attached. This is the ovary, inclosed in the lower part of the calyx, which has become incorporated with it. When mature, it will form a small, one-seeded fruit called an *akene*. Can

you see the ovule? Where is it attached? (Use a mature akene for this purpose.) In most plants of this family, the akene is surmounted by delicate hairy bristles, as in the dandelion, wild lettuce, and groundsel; or by small chaffy scales, as in the sneezeweed and sunflower, and sometimes by hooks and barbed hairs, like those of the tickseed, bur marigold, and cocklebur. These appendages constitute the *pappus*. They are modifications of the sepals, and serve an important purpose in aiding the distribution of the seed. Can you

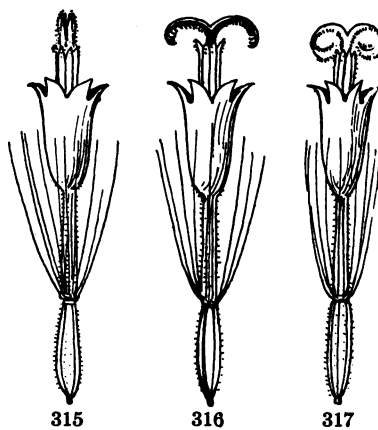


FIGS. 309-314. — Akenes of the composite family: 309, mayweed (no pappus); 310, chicory (pappus a shallow cup); 311, sunflower (pappus of two deciduous scales); 312, sneezeweed (*Helenium*, pappus of five scales); 313, sow thistle (pappus of delicate downy hairs); 314, dandelion, tapering below the pappus into a long beak. (After GRAY.)

suggest some of the ways in which they may aid in accomplishing this object?

235. The stamens and pistil. — Remove the corolla of a disk flower carefully so as not to disturb the inclosed organs, and notice how the stamens are united into a tube by their anthers. Flatten out the tube and make an enlarged sketch of it, showing the long, narrow shape of the anthers and their mode of attachment. Can you make out how they open to discharge their pollen? Examine one of the younger florets near the center of the disk, and observe that the tip of the style is inclosed in the anther tube with the lobes of the stigma pressed tightly together by their inner faces (Fig. 315), so that it is impossible for any of the pollen to reach the stig-

matic surface. It remains in this position till the anthers have shed their pollen, then, as may be seen by examining an older flower, the style begins to elongate, pushing up the pollen that has fallen on the hairy outside of the closed stigma, and forcing it out of the corolla tube, where it can be scattered by insects among the other flowers of the cluster. When the pollen of its own floret has been thus disposed of, the stigma lobes open and curl outward, ready to receive the pollen from other flowers. This arrangement is practically universal among plants of the composite family; can you divine its object? It will be shown later, that much larger and stronger seeds are produced when the pistil is pollinated from a different flower, or, better still, from a different plant of the same species; hence, you see what a useful adaptation this is.



FIGS. 315-317. — Flowers of *Arnica montana*, showing successive stages in pollination: 315, pistil just extruding from anther tube, covered with pollen, but with stigmatic surfaces closed; 316, stigma opened and mature; 317, stigma recurved to receive pollen from its own or neighboring anthers if foreign pollen has not reached it.

236. Nature of a composite flower. — It will be evident, from the examination just made, that the daisy, dandelion, sunflower, etc., are not single flowers, but compact heads of small blossoms so closely united as to appear like a single individual; hence they are said to be *composite*, or *compound*. They are the most numerous and widely disseminated of all plants, comprising one seventh of the entire flowering vegetation of the globe, and are regarded by botanists as representing the most advanced stage of floral evolution. Can you point out some of the adaptations to which their success in solving the problems of plant life is due? (164.)

IV. SPECIALIZED FLOWERS

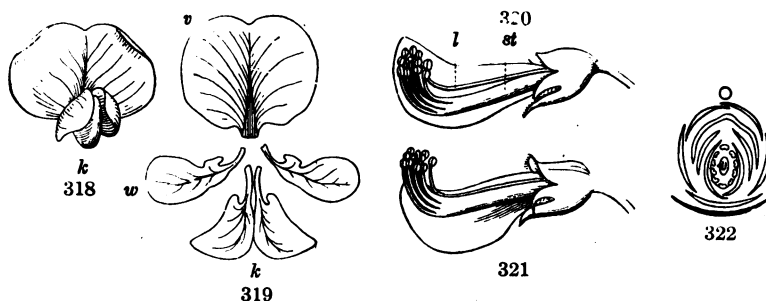
MATERIAL. — For spring and early summer: sweet pea, black locust, wistaria, lupine, or any of the characteristic butterfly-shaped flowers of the pea family. For autumn or late summer: tropæolum, monkshood, or a bilabiate flower — snapdragon, digitalis, dead nettle, salvia, catalpa, etc. — of the mint or figwort family.

237. Irregularity and specialization. — Irregularity and bilateral regularity are, as a rule, indicative of specialization, or adaptation to a particular purpose, such as the ready distribution of pollen, or its protection against injury. These adaptations are more noticeable in the corolla than in other parts, and hence flowers of this kind are usually classed according to the shape of their corollas. The most highly specialized flowers in this respect are the orchids, but they are too rare and difficult of access to be available objects for study. The most familiar and widely distributed kinds of specialized corollas are the *bilabiate*, or two-lipped, and the *papilionaceous*, or butterfly, forms. The first is characteristic of the mint and figwort families, of which the toadflax, sage, and catalpa are familiar examples. The second comprises the well-known papilionaceous flowers of the pea family, named from the Latin word *papilio*, a butterfly, on account of their general resemblance to that insect.

238. Dissection of a papilionaceous flower. — Sketch a blossom of any kind of pea or vetch as it appears on the outside. Are the sepals all of the same length and shape? If not, which are the shorter, the upper or the lower ones?

Turn the flower over and examine its inner face. Notice the large, round, and usually upright petal at the back, the two smaller ones on each side, and the boat-shaped body between them, formed of two small petals more or less united at the apex. Press the side petals gently down with the thumb and forefinger and notice how the essential organs are forced out from the little boat in which they are concealed.

Observe how the end of the style is bent over so as to bring the stigma uppermost when the petals are depressed. Imagine the legs of a bee or a butterfly resting there as he probed for honey; with what organ would his body first come in contact when he alighted? If his thorax and abdomen had previously become dusted with pollen when visiting another flower, where would the pollen be deposited? Do you notice anything in the color, shape, or odor of this flower that would be likely to attract insects? Have you ever observed insects



FIGS. 318-322. — Dissection of a papilionaceous flower: 318, front view of a corolla; 319, the petals displayed: *v*, vexillum, or standard; *w*, wings; *k*, keel; 320, side view with all except one of the lower petals removed, showing the essential organs protected in the keel: *l*, loose stamen; *st*, stamen tube; 321, side view, showing how the anthers protrude when the keel is depressed; 322, ground plan. (After GRAY.)

hovering around flowers of this kind; for example, in clover and pea fields, and about locust trees and wistaria vines? What kind of insects, chiefly, have you seen about them?

Remove the sepals and petals from one side, and sketch the flower in longitudinal section, showing the position of the pistil and stamens. Then remove all the petals, and spread in their natural order on the table before you, and sketch as they lie (Fig. 319). Label the large, round upper one, *standard* or *vexillum*; the smaller pair on each side, *wings*, and the two more or less coherent ones in which the pistil and stamens are contained, *keel*.

239. The stamens. — Count the stamens, and notice how they are united into two sets of nine and one. Stamens

united in this way, no matter what the number in each set, are said to be *diadelphous*, that is, in two brotherhoods. Notice the position of the lone brother, whether below the pistil — next to the keel — or above, facing the *vexillum*. Would the projection of the pistil, when the wings are depressed, be facilitated to the same extent if the opening in the stamen tube were on the other side, or if the filaments were *monadelphous* — all united into one set? Flatten out the stamen tube, or sheath, formed by the united filaments, and sketch it.

240. The pistil. — Remove all the parts from around the pistil, and sketch it as it stands upon the receptacle. Look through your lens for the stigmatic surface (223). See if there are any hairs on the style, and if so, whether they are on the front, the back, or all around. Can you think of a use for these hairs? Notice how the long, narrow ovary is attached to the receptacle; is it sessile, or raised on a short footstalk? If the latter, label the footstalk, *stipe*. Select a well-developed pistil from one of the lower flowers, open the ovary parallel with its flattened sides, and sketch the two halves as they appear under the lens. Notice to which side the ovules are attached, the upper (toward the *vexillum*) or the lower, and label it, *placenta*. How many locules has the ovary? How many carpels? How can you tell (216)?

241. Plan of the flower. — Diagram the flower in horizontal and vertical section, and decide upon the following points: —

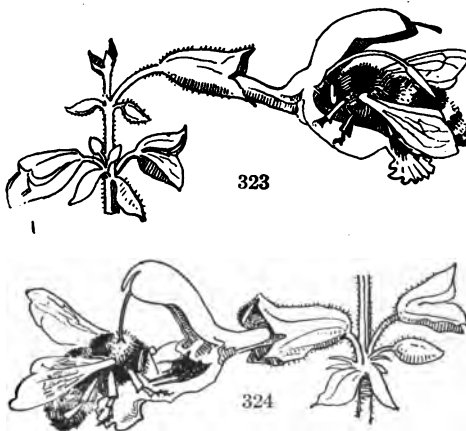
Numerical plan
Symmetry
Regularity
Union of parts
Position of the ovary

242. Significance of these distinctions. — These distinctions are important to remember, not only because they are very useful in grouping and classifying plants, but because they mark successive stages in the evolution of the flower. In general, flowers of a primitive type and less advanced

organization are characterized by having their organs free and hypogynous, while the more highly developed forms show a tendency to consolidation and union of parts, and the epigynous mode of insertion. Irregularity also, since it indicates specialization and adaptation to a particular purpose, may be regarded as a mark of advanced evolution.

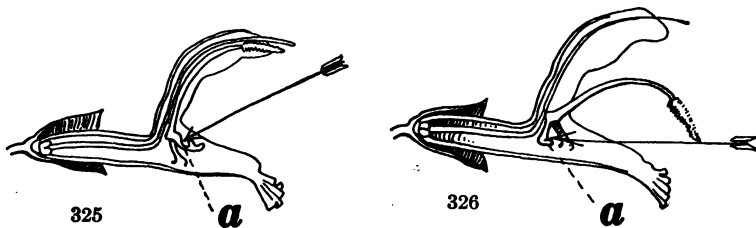
243. Dissection of a bilabiate flower.

— Make a similar study of the flower of a salvia, dead nettle, catalpa, or other specimen of the bilabiate kind. Make diagrams



FIGS. 323, 324. — *Salvia*: 323, a newly opened flower, showing the pollen-covered anther striking the back of a visiting bee; 324, an older flower, with the protruding pistil rubbing against the back of a bee covered with pollen from a younger flower.

and report as to (1) numerical plan; (2) presence or absence of parts; (3) regularity; (4) union of parts; (5) position of ovary. Observe especially the relative position of stigma



FIGS. 325, 326. — *Salvia*: 325, longitudinal section through a flower, showing the rocking connective which is struck at *a* by a visiting insect; 326, section of the same flower after being visited, showing the lower arm of the connective pushed back and lowering the anther.

and anthers; is it such that the pollen can reach the stigma without external aid? Does the peculiar shape of the corolla serve any other purpose than to attract the attention of

insect visitors by its conspicuous appearance? What is the use of the projecting underlip? Is it any convenience to a bee, for instance, to have a platform to rest on while gathering pollen or honey? What is the use of the arched upper lip? Cut it away and notice the exposed condition of the stamens and pistil. Turn a flower upside down; what would be the effect on a visiting bee or butterfly? (Exps. 83, 84.)

244. Morphology of the flower. — We have seen that the venation of petals and sepals corresponds in a general way with that of foliage leaves of the class to which they belong, and that their arrangement around their axis is analogous to the arrangement of foliage leaves on the branch.

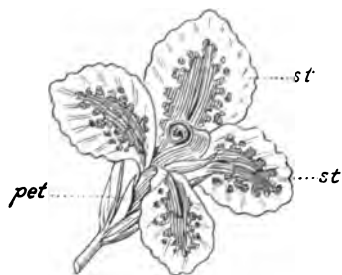


FIG. 327. — Staminodia, transformed stamens of *canna stimulator*: *pet*, petals; *st*, staminodia.

In our study of inflorescence, it was observed that flowers and flower buds occur in the same positions where leaf buds occur, and that they are subject to the same laws of arrangement and growth. We

learned, also, in our study of leaves, something about the wonderful modifications that these organs are capable of undergoing; and finally, an examination of a number of different flowers has shown them capable of undergoing modifications to an equal or even greater extent, and examples of the transition of almost any floral organ into another may be observed by one who will take the trouble to look for it. Stamens and petals are found in all stages of transformation, from the slightly flattened filament of the star-of-Bethlehem, or the yellow



FIG. 328. — Flower of a cactus (*cercus greggii*), showing transition from scales to petals.

pollen speck on the petal of a rose, to the brilliant staminodia, or transformed stamens of the canna (Fig. 327), which simulate petals so perfectly that their real nature is never suspected by the ordinary observer. The transition from spines and bracts to the brilliant corolla of the cactus (Fig. 328) is so gradual that we are hardly aware of it till we examine a specimen and see it actually going on before our eyes.

It must not be supposed, however, that an organ is ever developed as one thing and then deliberately changed into something else. When we speak loosely of one organ being modified into another, the meaning is merely that it has developed into one thing instead of into something else that it was equally capable of developing into.

245. The course of floral evolution. — For the reasons mentioned, the flower is regarded as merely a branch with modified leaves and the internodes indefinitely shortened so as to bring the successive cycles into close contact, the whole being greatly altered and specialized to serve a particular purpose. With this conception of the nature of the flower, we can readily see that the less specialized its organs are and the more nearly they approach in structure and arrangement to the condition of an undifferentiated branch, the more primitive and undeveloped is the type to which it belongs. On the other hand, if the parts are highly specialized and widely differentiated from the crude branch, a proportionately high stage of floral evolution is indicated.

V. FUNCTION AND WORK OF THE FLOWER

MATERIAL. — For this exercise, flowers of the mallow family — hollyhock, abutilon, mallow, hibiscus, cotton, okra, etc. — are particularly recommended because they have pollen grains so large that they can be studied fairly well with a hand lens. Lily, tulip, iris, etc., will also meet all essential conditions of the study outlined in the text. A strand of silk from a pollinated ear of corn is an excellent example for showing the growth of the pollen tube, under the microscope.

APPLIANCES. — A compound microscope; a watch crystal; sugar solution of 5 to 15 per cent.

EXPERIMENT 77. TO SHOW THE GERMINATION OF POLLEN GRAINS. — Put a drop of 5 per cent sugar solution into a watch crystal or a concave slide, seal by smearing the edges with vaseline, and cover with a glass to keep out the dust. Examine at intervals of five minutes under the microscope (a hand lens will show the result with the specimens recommended, though not so well), and the pollen grains will be observed to send out long filaments or tubes into the sirup, as a germinating seedling sends its radicle into the soil.

246. Office of the flower. — The one object of the flower is the production of fruit and seed, and all its wonderful specializations and variations of form and color tend either directly or indirectly to this end.

247. Pollination and fertilization. — It was stated in 215 that only in very exceptional cases can seed be developed unless some of the pollen reaches the stigma. This act, called *pollination*, is an essential step in seed production, but is not sufficient to secure that end unless it leads to the process known as *fertilization*. Successful pollination is a necessary preliminary to fertilization, and the one begins where the other ends.

248. The next step toward fertilization. — Examine with a lens the pollinated pistil of a mallow, lily, or other large flower, and notice the flabby, withered appearance of grains that have stood for some time on the stigma, as compared with those of a newly opened anther. Can you account for the difference? Touch the tip of your tongue to the stigma, or apply the proper chemical test, and it will be seen that the sticky fluid which it exudes, contains sugar. Refer to Exp. 77 and say what effect this substance has on the pollen.

249. The pollen tube. — The same thing happens when a pollen grain falls on the moist surface of the stigma. It begins to germinate by sending a little tube down into the substance of the pistil, and the withered appearance of the grains on the stigma results from the nourishment in them having been exhausted, just as the endosperm of the seed is exhausted when the embryo begins to germinate. Here, how-

ever, the analogy ends, for the pollen tube is not adapted, like the radicle of the seedling, to absorb and convey nourishment up to the other parts, but to feed and carry down to the ovary two small bodies called *generative cells*, which it discharges there, and then its work is done and it disappears. So it must be borne in mind that when we speak of the germination of the pollen grains, we mean something really very different from the germination of a seed.

250. The course of the pollen tube. — Cut the thinnest possible section through a freshly pollinated pistil and place under the microscope. Watch the pollen tubes from the grains on the stigma as they descend through the style toward the ovary. A pollinated strand of corn silk — which is only a very much elongated style — is excellent for this purpose. It is so thin and transparent that no section need be made, and the tube can be traced as it works its way down through the entire length of the threadlike style to the young grain, or ovary, on the cob. The time required for the tube to penetrate to the ovary varies in different flowers according to the distance traversed and the rate of growth. In the crocus it takes from one to three days; in the spotted calla, about five days; and in orchids, from ten to thirty days. As a rule, it occupies only a few hours. Sometimes the pistil is hollow, affording a free passage to the pollen tube; in other cases, it is solid, and the growing tube eats its way down, as it were, feeding on the substance of the pistil as it grows. How is it in the flower you are examining? It takes a grain of pollen to fertilize each ovule, and where more than one seed is produced to a carpel, as is commonly the case, at least as many pollen tubes must find their way to each locule of the ovary as there are ovules — provided all are fertilized.

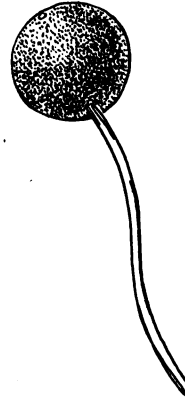


FIG. 329. — A pollen grain emitting a tube (magnified).

251. Fertilization. — When a pollen tube has penetrated to the ovary, it next enters one of the ovules, usually through

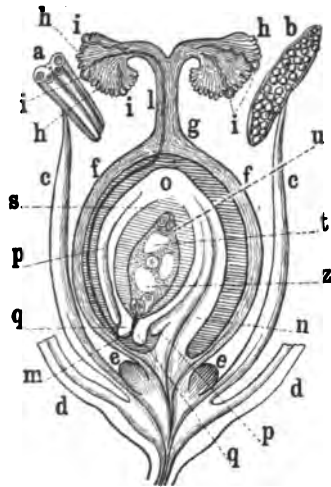


FIG. 330. — Diagram of a simple flower, showing course of the pollen tube: *a*, transverse section of an anther before its dehiscence; *b*, an anther dehiscing longitudinally, with pollen; *c*, filament; *d*, base of floral leaves; *e*, nectaries; *f*, wall of carpels; *g*, style; *h*, stigma; *i*, germinating pollen grains; *m*, a pollen tube which has reached and entered the micropyle of the ovule; *n*, stalk of ovule; *o*, base of the inverted ovule; *p*, outer integument or testa; *q*, inner integument; *s*, rudimentary ovule; *t*, cavity of the embryo sac; *u*, its basal portion; *z*, oosphere.

the micropyle (Fig. 330, *m*). There it penetrates the wall of a baglike inclosure called the *embryo sac* (Fig. 330, *u*, *t*, *z*), where one of the generative cells emitted by the pollen tube fuses with a large cell contained in the embryo sac, known as the *germ cell*, or *egg cell* (Fig. 330, *z*). The fusion of these two bodies is what constitutes fertilization. The cell formed by their union finally develops into the embryo, and the other contents of the sac into the endosperm, and the ripened ovules become seeds.

252. Stability of the process of fertilization. — The phenomena that characterize the functions of fertilization and reproduction are the most uniform and stable of all the life processes, varying little not only in different species and

orders, but throughout the whole vegetable kingdom. And since these functions furnish a more reliable standard for judging of the real affinities of the different groups than do mere external resemblances, which are more liable to variation and may often be accidental, they have been chosen by botanists as the ultimate basis for the classification of plants.

253. Embryology. — The study of the developing plantlet, known as *embryology*, is a comparatively recent branch of

science, and has greatly enlarged our knowledge of the life history of both plants and animals, by bringing to light resemblances that exist between the most widely divergent species in their earlier stages of development and thus showing traces of a common origin. It has shown further, that every individual plant or animal, in its development from the embryo to the mature state, passes briefly through stages apparently similar to those which the species has traversed in the course of its evolution. This summary repetition, by the individual, of the evolutionary progress of its kind is known as the *biogenetic law*, and through its intelligent application some of the most intricate problems in both physiology and psychology have been solved.

Practical Questions

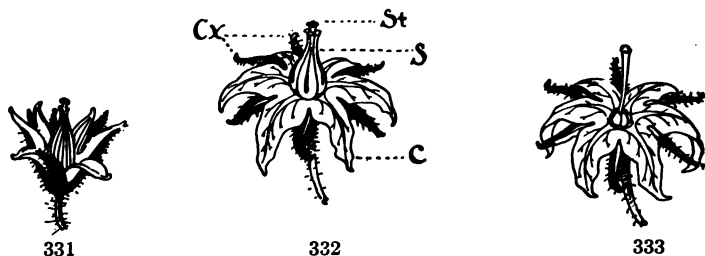
1. Does the biogenetic law throw any light on the resemblances sometimes observed between leaves of different ages in unlike species; for example, the fig and the mulberry? (170; Field Work, p. 195.)
2. Can you name any other examples of plants or parts of plants which show mutual resemblances in their early stages that do not exist at maturity?
3. Are there other causes than those acting under the biogenetic law to which some of these resemblances may be referred; for instance, the down and waxy coating on young leaves and bud scales? (148, 207.)

VI. HYBRIDIZATION

MATERIAL. — Several potted plants of tulip, lily, or any attainable large flowered kind; or preferably a small plot in a garden or nursery.

APPLIANCES. — A pair of dissecting scissors, a camel's-hair brush, and some paper bags.

EXPERIMENT 78. DOES IT MAKE ANY DIFFERENCE WHETHER A FLOWER HAS ITS OVULES FERTILIZED WITH ITS OWN POLLEN OR WITH THAT OF ANOTHER FLOWER OF THE SAME KIND? — Carefully remove the *unopened* anthers from a bud of a tulip, or other large flower just ready to unfold (Fig. 331), inclose the mutilated bud in a small paper bag until the stigma is mature, as shown by stickiness, then transfer to it with a camel's-hair brush some pollen from another flower. On the stigma of a second flower of the same kind place some of its own pollen, and cover with a paper bag until the stigma withers, to keep foreign pollen from reaching it by means



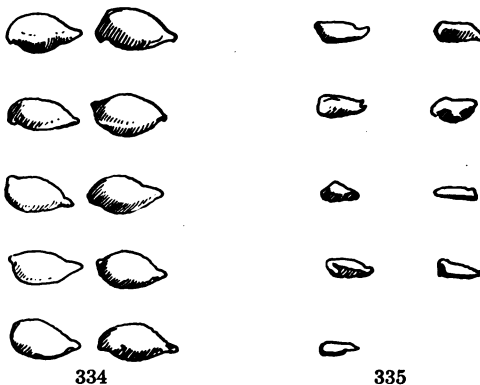
FIGS. 331-333. — Flower of Lorillard tomato: 331, newly opened bud, showing stage in which the stamens should be removed; 332, mature flower: *cx*, calyx; *c*, corolla; *s*, stamens; *st*, stigma; 333, flower with stamens removed for pollination. (Natural size.)

of wind or insects. Watch until seeds are matured. Which flower produces the more seeds or the better ones? Plant the seeds; which produce the more vigorous progeny?

EXPERIMENT 79. CAN A FLOWER BE FERTILIZED WITH POLLEN OF A DIFFERENT KIND? — Dust the stigma of a tulip or a lily, from which the stamens have been removed, with pollen from a narcissus, iris, or amaryllis. Cover to protect from wind and insects. Are any seeds produced?

Experiments of this kind, to be conclusive, ought to be performed on a sufficient number of plants and through at least three generations. This is hardly practicable for class work, but students who are specially interested in the subject may carry on experiments at home, or supply their place, to some extent, by observations out of doors, if there are any farms or gardens accessible.

254. Self-fertilization takes place when a stigma is pollinated from the same flower. Horticulturists have long known that continued self-fertilization, or "inbreeding" as it is called by nurserymen, tends to deteriorate a stock; but



FIGS. 334-335. — Seeds of Bartlett pear, showing the advantage of cross-fertilization: 334, cross-fertilized; 335, self-fertilized;



FIG. 336. — Showing the effect of in-breeding on corn in one generation. The two left-hand rows are from self-fertilized seed.

Charles Darwin was the first to explain, by a series of painstaking experiments, the meaning of those careful adjustments which the more highly organized plants, as a rule, have developed to guard against it.

255. Cross-fertilization is effected by the pollination of a stigma from another flower of the same variety or species. As used by practical horticulturists, the expression means that the two factors, pollen and ovule, belong to different plants. Since pollination is the necessary antecedent to fertilization, and the only means by which we can control it, the breeder's part in crossing is concerned with this act only and nature does the rest. Darwin's experiments — and they are confirmed by the experience of plant growers everywhere

— prove that the offspring from crossing different plants of the same kind is usually stronger and more productive than that from self-fertilized ones; and if the parent stocks are grown in different places and under different conditions, the offspring is more vigorous than that from the same kind of plants grown under like conditions. For instance, plants from crossed seeds of morning-glory vines growing near each other exceeded in height those from self-fertilized seeds as 100 : 76; while the offspring of plants growing under different conditions exceeded those of the other cross, in height, as 100 : 78; in number of pods, as 100 : 57, and in weight of pods, as 100 : 51. Knowledge of this kind, when applied to the raising of fruits and grains for market, is of incalculable value to gardeners and farmers, and also to the amateur who raises fruits or flowers for pleasure.

256. Hybridization is the crossing of two plants of different species or of widely separated varieties of the same species. The resulting offspring is a *hybrid*. Hybridization can take place only within certain limits. If the species are too unlike, the pollen will either not take effect at all, or the resulting offspring will be too weak and spindling to live; or if they survive, will not be able to set seed (Exp. 79).

257. Effects of hybridization. — The most important practical uses of hybridizing are: (1) it “breaks the type” by causing plants to vary, and thus gives the breeder a fresh starting point for a new strain; and (2) when the parent species are not too unlike, it accentuates the good effects of crossing, and sometimes gives rise to offspring greatly surpassing either parent in size and vigor. In regard to variability it may act in three ways: (1) the hybrid may wholly resemble one parent or the other, in which case there is, of course, no variation; (2) it may resemble one parent more than the other; or (3) it may show a blending of the characters of the two, as when a cross between a red poppy and a white gives rise to a light pink, or a mixed red and white variety. In the first two cases, the characters of the parent



PLATE 11.—Hybrid between a red and a white carnation, showing characters intermediate between the two parents.

that manifest themselves are said to be *dominant*; those which do not, *recessive*.

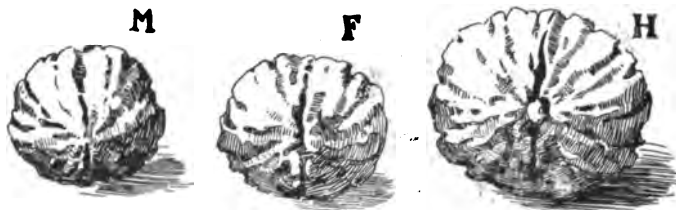


FIG. 337. — Effect of hybridization between related species in imparting superior vigor to offspring: *M*, Californian black walnut (*Juglans californica*), male parent; *F*, Eastern black walnut (*J. nigra*), female parent; *H*, hybrid.

258. Mendel's Law. — So long ago as the middle of the last century it was discovered by Gregor Mendel, an Austrian investigator, that hybrids vary in certain cases according to a fixed law, by means of which the proportionate share of the characteristics of the two parent forms inherited by the offspring can be foretold with almost mathematical precision. The controversy over Darwin's "Origin of Species," which was raging at the time, caused Mendel's discoveries to be overlooked for a generation, and it is only within the last

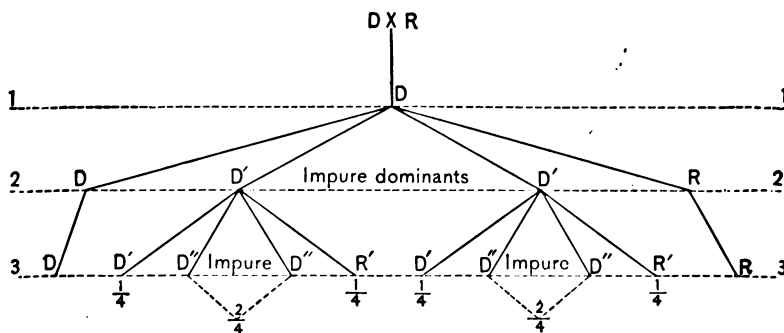


Diagram illustrating Mendel's Law.

few years that their importance has been realized. The principle of variation demonstrated by him in a series of experiments, and confirmed by later investigators is, briefly,

this: If two parents differing in some fixed characteristic be crossed, the entire offspring, in the first generation, will be like the parent possessing the dominant quality. If all the seed of this generation is planted and carefully protected from foreign pollen, its offspring composing the second generation from the parents will vary in the proportion of $\frac{3}{4}$ dominants (D, D' , line 2 of the diagram) to $\frac{1}{4}$ recessives (R). Planting *all* the seeds of the second generation and carefully shielding their progeny from foreign pollen, we get from D , line 2, all pure dominants (D , line 3) — that is, plants producing only their own type, and from R , line 2, all pure recessives (R , line 3). But from each of the two sets of dominants, $D'D'$, line 2, marked “impure” in the diagram, and so called because their seeds may produce both dominants and recessives, we get the same result as in the second generation, namely: pure dominants ($D'D'$, line 3), pure recessives ($R'R'$, line 3), and impure dominants ($D''D'', D''D''$, line 3). If it were possible to distinguish the seeds of these impure dominants before germination and plant them only, for no matter how many generations, the result would always be approximately the same, — $\frac{1}{4}$ pure dominants, $\frac{1}{4}$ pure recessives, and $\frac{3}{4}$ impure dominants capable of producing both dominants and recessives in the proportion of 3:1.

259. Practical applications. — Four principles of great importance to plant breeders follow from this law in cases to which it applies: (1) the absence of variation in the first generation of hybrids is no sign that it may not occur later; (2) pure recessives always breed true; hence, if they show the desired character, no further selection is necessary for that character; (3) pure dominants always breed true, but the distinction between pure and impure is usually not apparent in one generation; (4) the descendants of “impure” parents cannot be depended upon to come true to either type, but impure dominants may breed recessives, and *vice versa*, with the presumption, however, of 3:1 in favor of dominants.

Practical Questions

1. Would hybridization account for some of the diversities mentioned in 170? (See 257.)
2. To what cases would it not apply? (256; Exp. 79.)
3. Would it be worth while to try to hybridize the potato and squash? The squash and pumpkin? The lily and rose? Sweetbrier and wild rose? Apple and peach? Wild crab and sweet apple? Blackberry and strawberry? Blackberry and raspberry? Lemon and watermelon? Lemon and orange? Why, or why not, in each case? (256; Exps. 78, 79.)

VII. PLANT BREEDING

MATERIAL. — If practicable, visit a market garden, a florist's establishment, or, lacking these, the fruit and vegetable stalls of a city market.

260. Fixing the type. — It is the tendency of plants to vary under the influence of climate, soil, food supply, crossing, and other causes perhaps unknown to us, that makes the plant breeder's art possible. When a horticulturist sets out to produce a new fruit or vegetable, he first forms in his mind a clear idea of what he wants — whether increase of yield or size, resistance to cold, drought, or disease, improvement in flavor, color, shape, etc., or change in the time of maturing or flowering (early and late varieties). Suppose, for instance, he wishes to produce an oxeye daisy with all the disk florets changed to white ones like the rays. He will begin by selecting plants with the greatest number of rays and the most conspicuous ones that he can find, and sowing the seeds of the flowers which show the greatest tendency to the development of these qualities. He will continue this process from generation to generation, rigorously destroying all specimens that do not approach nearer the ideal sought, until all disposition to "rogue," as the tendency to revert is called, has been eliminated. When variations cease to occur and the seed of the new variety always "come true," the type is said to be *fixed*; though some care will always be necessary to keep it so, as the influence of changed surroundings and the danger of mixture with foreign pollen must always be provided against.

261. Survival of the fittest. — In the fierce struggle continually going on among both plants and animals for food, shelter, and elbow room in the world, any individual that happens to vary in a way which adapts it to its surroundings a little better than its rivals, has an advantage that will enable it to survive when less favored members of the species will perish. Its offspring, or some of them, may inherit this quality and transmit it, with the attendant advantage, to their posterity, and so on, till that particular breed outstrips all competitors, and in time, as the less favored intervening forms die out, becomes differentiated



FIG. 338. — A field of pumpkins grown from selected seed.

as a new species. This is, in brief, the doctrine of natural selection and the survival of the fittest.

262. Artificial selection. — Artificial selection enables the breeder to accomplish more quickly what nature appears to do by the slow process of natural selection. It is by this means that our choicest fruits and vegetables have been developed from greatly inferior, and sometimes inedible, wild forms. Plants respond so readily to the influence of selection, and the changes brought about by it are so rapid, that new styles of fruits and flowers succeed each other in

the market with almost as great frequency and in as ready response to demand as the new styles of women's bonnets and gowns in the shop windows.

263. Causes of variation. — While man cannot directly force plants to vary in any given direction, he can hasten the process of variation by crossing, or by changing the conditions under which they are growing. This is called "breaking the type." Hybridization furnishes the readiest means to this end. Change of food supply, especially if accompanied by excess of nourishment, is probably the expedient that ranks next in effectiveness. Light, temperature, moisture,

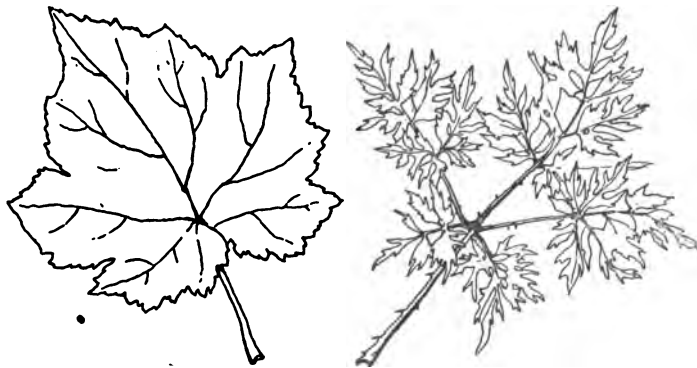


FIG. 339. — Variation in blackberry leaves due to hybridization.

character of the soil, exposure to wind, and the like, also have their influence; and in adapting themselves to changes in these various conditions, plants are apt to exhibit an unusual number of variations, when removed from one locality to another, especially if the difference in soil and climate is very marked. Now comes the breeder's opportunity. By taking advantage of such variations as may occur either spontaneously, or as the result of his efforts to break the type, he will generally find some that will meet his requirements; and knowing the effect produced by different conditions, he can, to a certain extent, influence the course of variation in the direction desired, by subjecting his specimens to the

conditions that tend to produce it. If he wishes to develop a dwarf variety, for instance, he will take notice that overcrowding, lack of nourishment, and cold tend to produce that result in nature, and by acting on this hint he can direct his efforts more intelligently. He will learn, too, not to waste time in trying to breed a plant contrary to its nature. He must not expect to gather figs from thistles by any art of selection or skill in culture. By attention to Mendel's law, a still further saving of time and labor may be effected.

It is obvious, from what has been said, that a breeder's chance of finding what he wants will be greater in proportion to the number of individual plants he has to choose from. For this reason, a horticulturist sometimes uses thousands and hundreds of thousands of specimens of a single kind in conducting his experiments. In this way he compresses into a short space of time the advantage that nature can gain only by spreading her random experiments over a long series of years, or even centuries.

264. Mutation and variation. — There are at least two ways in which changes in vegetable and animal forms are thought to occur: (1) by the preservation and fixation through selection and heredity, of slight differences that may appear from time to time, such divergences being called "fluctuating variations"; (2) by the appearance now and then, due to causes as yet unknown, of definite and sudden changes creating a new form at a single, though perhaps small, leap. When such a change is temporary and passes away with the individual in which



FIG. 340. — Mutation in twin ears of corn, showing the sudden variations that sometimes occur, by which a new type may be provided without the labor of selection.

it first appeared, it is called a "sport," and leads to no important results; but when it is inherited by the offspring, so that it is capable of giving rise to a new species, it constitutes a "mutation." The value of a mutation to breeders in saving time and trouble is obvious. Professor Hugo de Vries, a Dutch botanist, was the first to call attention to the importance of mutation and its bearing upon the production of new species.

265. Factors in the evolution of species. — Variation, heredity, and selection are the three principal agents underlying all changes, whether for the improvement or deterioration of living organisms. The influence of external surroundings in keeping up a variation once begun, or in starting new ones, is also a factor that cannot be disregarded. It is for this reason that natural species are so much more stable than those brought about by man. The former, being evolved in response to natural conditions, are liable to change only as alterations in their surroundings are brought about by the slow operation of natural causes. But the types resulting from the breeder's art, produced as they often are in response to human demands and in direct opposition to the requirements of natural conditions, are in a sense purely artificial, and can be preserved only by keeping up the artificial surroundings by which they were developed. Hence, the importance of diligent cultivation and constant care and tillage, without which the most carefully selected stocks may quickly "run out" and degenerate into worthless forms.

Practical Questions

1. Which are the more pliable to the breeder's art, annuals or perennials? Why? (91, 93, 262, 263.)
2. What advantage is gained by using buds and grafts instead of seedlings in making new varieties of fruit trees? (257, 259, 260.)
3. Would it be practicable to breed new varieties of slow-growing forest trees, like oak, cypress, redwood, from seeds? Why or why not? (93, 262, 263.)
4. Can you account for the existence of the numerous intermediate forms between the different species of oaks found in nature? (255, 257.)

5. If a breeder wished to produce a sweet-scented daisy or pansy, how would he make his selections? (260.)

6. Which would be the more useful for his purpose, a plant that showed a general tendency to variability, or one that remained steadily fixed to its type? (260.)

7. What could he do to break the type? (263.)

8. Would an intelligent breeder set out to produce edible roots and tubers from wheat or barley? (263.)

9. Would he think it worth while to try to develop a fleshy fruit from a filbert or a walnut tree? From a haw? From sheepberry and black haw? From tupelo (ogeechee lime)? (263.)

10. Suppose a florist should wish to change the color of a rose from pink to deep red; how could he hasten the process? (257, 263.)

11. Explain why it is so much easier to produce new varieties of plants when there are already many kinds in existence, as, for example, the rose, peach, and chrysanthemum. (255, 256; Exps. 78, 79.)

VIII. ECOLOGY OF THE FLOWER

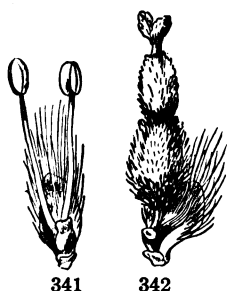
A. THE PREVENTION OF SELF-POLLINATION

MATERIAL. — Any kind of unisexual flowers obtainable. Some good examples for illustrating points mentioned in the text are: for spring and early summer, catkins of almost any of our common forest trees, — oak, hickory, willow, poplar, etc.; tassels and young ears of early corn; for summer and early fall, flowers of late corn, and of melon, squash, pumpkin, or others of the gourd family. Examples of *dichogamy* are: evening primrose, showy primrose (*Oenothera speciosa*), willow herb (*Epilobium*), dandelion, artichoke, sunflower, or any of the composite family; of *dimorphism*: English primrose (*Primula*), loosestrife (*Pulmonaria*), bluets (*Houstonia*), partridge berry; *cleistogamic*: fringed polygala, violets. Peanuts, while not technically classed as cleistogamic, are strictly close-fertilized, and approach the type so nearly that they may be used as an illustration.

266. Ecology is the study of plants and animals in relation to their surroundings. The principal modifications that flowers undergo in this respect are in adapting themselves for (1) pollination, and (2) protection.

267. Unisexual flowers. — The advantages of cross fertilization were shown in the last two sections. It was also

shown that the first step taken by the breeder to secure this result is to render the flower incapable of self-fertilization,



FIGS. 341, 342.—
Unisexual flowers of willow: 341, staminate; 342, pistillate.

by removing the stamens. Nature accomplishes the same purpose by the more effectual expedient of providing imperfect, or *unisexual* flowers, in which stamens only, or pistils only, occur in the same flower. When the stamens alone are present, the flower is said to be staminate, or *sterile*, because it is incapable of producing seeds of its own, though its pollen is a necessary factor in seed production. If, on the other hand, the ovary is present and the stamens absent, the flower is pistillate and *fertile*; that is, capable of producing fruit when impregnated with pollen. Sometimes both stamens and pistils are wanting, as in the showy corollas of the garden "snowball," the hydrangea, and the rays of the sunflower. Such blossoms are said to be *neutral*, from the Latin word *neuter*, meaning neither, because they have neither pistils nor stamens. They can, of course, have no direct part in the production of fruit, but are for show merely. (231.)

268. Monœcious and diœcious plants.—When both kinds of flowers, staminate and pistillate, are borne on the same plant, as in the oak, pine, hickory, and most of our common forest trees, they are said to be *monœcious*, a word which means "belonging to one household"; when borne on separate plants, as in the willow, sassafras, and black gum, they

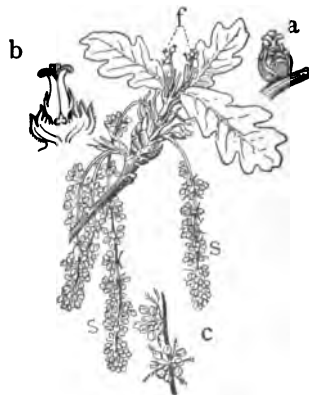
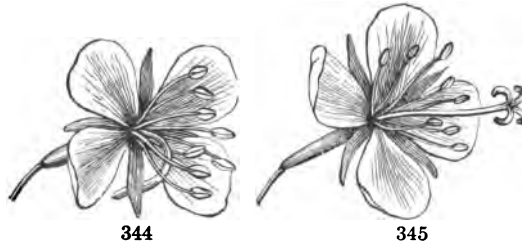


FIG. 343.—Twig of oak with both kinds of flowers: *f*, fertile flowers; *s*, *s*, staminate; *a*, pistillate flower, enlarged; *b*, vertical section of pistillate flower, enlarged; *c*, portion of one of the sterile aments, enlarged, showing the clusters of stamens.

are *diœcious*, or “of two households.” Draw a flowering twig of oak, pine, or willow. Where are the fertile flowers situated? Notice how very much more numerous the staminate flowers are than the fertile ones. Why is this necessary? (275.)

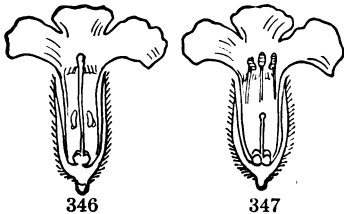
269. Dichogamy is the name applied to a condition where the stamens and pistils mature at different times, as in the evening primrose, oxeye daisy, and most of the composite family. It is a very common method in nature for preventing



FIGS. 344, 345.—Flower of fireweed (*Epilobium angustifolium*): 344, with mature stamens and immature pistil; 345, the same a few days older, with expanded pistil after the anthers have shed their pollen. (After GRAY.)

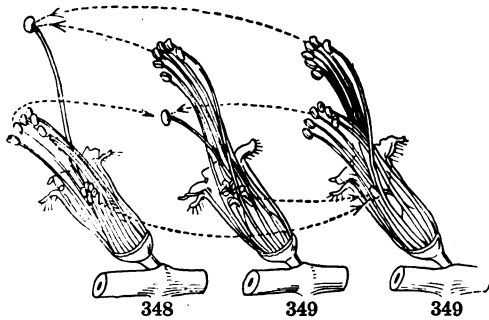
self-pollination, and quite as effective as the monœcious arrangement, since it renders the flowers practically unisexual.

270. Dimorphism denotes a condition in which the stamens and pistils are of different relative lengths in different flowers of the same species, the stamens being long and the pistils short in some, the pistils long and the stamens short in others. Flowers of this sort are said to be *dimorphous*, or *dimorphic*, that is, of two forms; and some species are even *trimorphic*, having the two sets of organs long, short, and medium, respectively, in different indi-



FIGS. 346-347.—Flower of pulmonaria: 346, long styled; 347, short styled.

viduals. Examples of dimorphic flowers are the pretty little bluets (*Houstonia cœrulea*), the partridge berry, the swamp loosestrife, and the English cowslip. Of trimorphic flowers we have examples in the wood sorrel and the spiked loosestrife (*Lythrum salicaria*) of the gardens. These flowers were a great puzzle to botanists until the celebrated naturalist,



FIGS. 348-350. — Three forms of loosestrife (*Lythrum salicaria*).

Charles Darwin, proved by experiment that the seeds produced by pollinating a dimorphous flower with its own pollen, or with pollen from a flower of similar form, are of very inferior quality to those produced

by impregnating a long-styled flower with pollen from a short-styled one, and *vice versa*.

271. "Nature abhors self-fertilization." — These are the three principal methods by which nature provides against self-fertilization. Other cases occur in which the relative position of the two organs is such that self-pollination is difficult, or impossible, as in the iris and bear's grass; or the pollen may be incapable of acting on the stigma of the flower that produced it. This aversion to self-fertilization is so great that many flowers, even when capable of it, will give preference to the pollen of another plant of the same kind, if dusted with both. From his observations on the behavior of plants in reference to this function, Charles Darwin drew the conclusion that "Nature abhors perpetual self-fertilization."

272. Cleistogamic flowers. — Apparent exceptions to this rule are the hidden flowers found on certain plants which seem to have been constructed with a special view to self-fertilization. They are called *cleistogamic*, or closed, because they never open, but are fertilized in the bud; and those of the fringed polygala do not even rise above ground at all. Flowers of this kind can be found on several species of violet, concealed under the leaves, close to the ground; and the flowers of the peanut, found in the same situation, while they open slightly, are close-fertilized and practically cleisto-

gamic. They are much more prolific than ordinary flowers, but are not common, and seem to be a provision against accident, for the plants producing them are generally provided with other flowers of the usual kind,—some, as the violet, having elaborate special adaptations for cross fertilization.

Practical Questions

1. Why does a strawberry bed sometimes fail to fruit well, although it may flower abundantly? (267, 268.)
2. Are berries found on all sassafras trees? On all buckthorns? Hollies?
3. Would a solitary hop-vine produce fruit? A solitary ash tree? (267.)
4. Why is a mistletoe bough with berries on it so much harder to find than one with foliage merely? (267, 268.)

B. WIND POLLINATION

MATERIAL. — In spring, catkins of forest trees, staminate and pistillate flowers of pine. At nearly all seasons, heads of grain and panicles of various kinds of grass can be obtained. For experiment, a potted plant of any kind, just about to bloom, may be used.

EXPERIMENT 80. TO TEST THE EFFECT OF SHUTTING OUT EXTERNAL AGENCIES. — Tie paper bags over flower buds of different kinds when nearly ready to open and leave until the flowers have withered. On removing the bags, mark with colored threads the flowers that had been covered, and watch until seed time. Do you notice any difference in the number, size, or weight of the seed produced by them and by those of the same kind left exposed? How do you account for the difference, if there is any? By what agencies could foreign pollen have been carried to the stigmas of the exposed flowers? If any of the covered specimens wither and drop their seed vessels without any attempt to fruit, examine a fresh flower, and see if it is capable of self-pollination.

As already explained, experiments of this kind, to be conclusive, should be tried on as many specimens as possible. The greater the number of species and individuals included, the better. Where it is not practicable to carry on experiments by the class, pupils who are interested can make them at home.

273. The problem of pollination. — When a plant has provided against self-pollination, its problem is only half solved,

as it must now depend upon the conveyance of pollen to the stigma by extraneous means.

274. Adaptations to wind pollination. — A very large number of plants, among which are included nearly all our

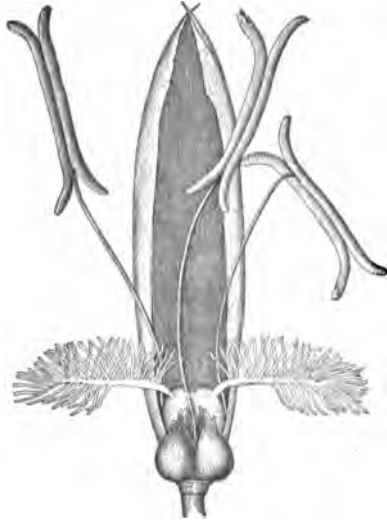


FIG. 351. — Feathery stigmas of a grass adapted to wind pollination.

principal forest trees, grains, and grasses of every kind, depend exclusively upon the wind for the distribution of their pollen. This being the case, it is, of course, an advantage to them to get rid of all unnecessary appendages that might hinder a free play of the wind among their flowers, and so they consist, as a rule, of essential organs only (Figs. 341, 342). Such flowers are often distinguished, however, especially among grasses and low herbs, by large, feathery stigmas that

are well adapted to catch and hold any stray pollen grains which may be floating in the air. Place a stigma of oat or other grass under the microscope and you will probably see a number of pollen grains clinging to its branches.

275. The disadvantages of wind pollination. — This is a very clumsy and wasteful method, however, for so much pollen is lost by the haphazard mode of distribution that the plant is forced to spend its energies in producing a vast amount more than is actually needed, and great masses of it are frequently seen in spring floating like patches of sulphur on ponds and streams in the neighborhood of pine thickets. Like those that are self-pollinated, wind-pollinated flowers are generally very inconspicuous, devoid of odor, and of all attractions of form or color, because they have no need of

these allurements to attract the visits of insects. Besides being wasteful, wind pollination is very uncertain. The pollen cannot be blown about very well unless it is dry, and in rainy weather it may all be rotted or washed away before it can reach the stigmas that are ready to receive it.

Practical Questions

1. Why do the flowers of oak, willow, and other wind-fertilized plants generally appear before the leaves? (274.)
2. Can you account for the showers of "sulphur" sometimes reported in the newspapers? (275.)
3. Do you see any connection between the feathery stigmas of most grasses and their mode of pollination? (274.)
4. Why are house plants not apt to seed so well as those left in the open? (Exp. 80.)
5. Why are the tassels of corn placed at the tip of the stalk? (274.)
6. Can you trace any connection between the winds and the corn crop? (274.)
7. If March winds should cease to blow, would vegetation be affected in any way? (274.)
8. Why are wind-fertilized plants generally trees or tall herbs? (274.)
9. Is it good husbandry to plant different varieties of corn or other grain in the same field, if it is desired to keep the strain pure? (255, 274.)
10. Is water a good pollen carrier? (275.)
11. What is the only class of plants it is likely to reach?
12. What is the only other agency, besides wind and water, by which this office can be performed?

C. INSECT POLLINATION

MATERIAL. — Half a dozen panes of glass, about 6×9; squares of bright-colored cloth or paper; a few spoonfuls of honey or sirup; perfumes of various kinds, preferably flower extracts; fetid and disagreeable smelling substances, such as a bit of decaying animal or vegetable matter. Observations on living plants can best be made out of doors or in a greenhouse, as opportunity offers.

EXPERIMENT 81. HAS THE COLOR OF FLOWERS ANY ATTRACTION FOR INSECTS? — Place half a dozen panes of ordinary window glass out of doors or in an open window to which insects can have free access. Lay under the first pane a piece of black paper or cloth, and under the others bright-colored pieces of red, blue, white, yellow, and purple. Drop on the center of each pane a little honey or sirup, and watch. Do insects show any color preferences? Which color attracts fewest visitors? Which most?

EXPERIMENT 82. DOES ODOR INFLUENCE INSECTS? — Try the same experiment with different odors, removing the bright colors and sprinkling some kind of perfume on each pane. Try also the effect of decaying meat and other malodorous substances. Are any insects attracted by these? What kinds? Does this account for the noisome smells of the "carrion-flower" and skunk cabbage? What kinds of insects are attracted by sweet-smelling substances? Do the greater number appear to be attracted by these, or by foul odors? Are flowers of the sweet-smelling or the foul-smelling kind more common in nature? Do insects seem to be more strongly influenced by colors or by odors?

276. The color of flowers, being an adaptation to changing external conditions, is a very unstable quality, and varies greatly within the limits of the same species. Even on the same stem, flowers of different colors are often found, due, probably, to hybridization. Yet, notwithstanding all this apparently random intermingling of hues, the range of color for each species is confined, approximately, within certain limits. Nobody has ever seen a blue rose or a yellow aster; and though the florist's art is constantly narrowing the application of this law, it still remains true that in a state of nature, certain colors seem to be associated together in the floral art gamut. Yellow is considered the simplest and most primitive color in flowers, and blue the latest and most highly evolved. Yellow, white, and purple, in the order named, are the commonest flower colors in nature; blue, the rarest. Do you see any relation between these facts and the color preferences of insects?

277. Advantages of insect pollination. — It is evident that this is a much more certain as well as a more economical method of securing pollination than through the haphazard agency of wind or water. In probing around for the nectar or the pollen upon which they feed, these busy little creatures get themselves dusted with the fertilizing powder, which they unconsciously convey from the stamen of one flower to the pistil of another. Insects usually confine themselves, as far as possible, to the same species during their day's work, and since less pollen is wasted in this way than would be done by

the wind, it is clearly to the advantage of a plant to attract such visitors, even at the expense of a little honey, or of a liberal toll out of the pollen they distribute.

278. Special partnerships. — Some plants have adapted themselves to the visits of one particular kind of insect so completely that they would die out if that species were to become extinct. The well-known alliance between red clover and the bumblebee was brought to light when the plant was first introduced into Australia. It grew luxuriantly and blossomed profusely, but would never set seed till the bumblebee was introduced to keep it company.



FIG. 352. — Pod of *yucca* pierced by the *Pronuba yuccasella*.

A remarkable partnership of this kind exists between the *pronuba*, or yucca moth, and the flowering yuccas, of which the bear's grass and Spanish bayonet are familiar examples. The pods of these plants are never perfect, but all show a constriction at or near the middle,



FIG. 354. — Moth resting on yucca blossom.

such as is sometimes seen in the sides of wormy plums and pears.

This is caused by the larvæ of the moth, which feed upon the unripe seeds. A glance under the nodding perianth of a yucca blossom (Fig. 354)

will show that the short stamens are curved back from the pistil in such a manner that, under ordinary circumstances, the pollen cannot reach the stigma except by the rarest accident. But the yucca moth, as soon as she has deposited her eggs in the seed vessel, takes care to provide a crop of



FIG. 353. — *Pronuba* pollinating pistil of yucca.

food for her offspring by gathering a ball of pollen in her antennæ and deliberately plastering it over the stigma (Fig. 353). In this way fertilization of the ovules and maturing of the fruit is secured. The larvæ feed on the unripe seeds



FIG. 355. — Upper boughs of a caprifig tree, showing an abundant crop of spring fruit.

for a time, but so few are destroyed in proportion to the number matured that the plant can well afford to pay the small toll charged in return for the service rendered.

279. Caprification of the fig. — A more complicated case of specialization is that of the Smyrna fig of commerce — the only one of the species that is capable of perfecting seeds. The

staminate flowers are borne on a separate tree, the caprifig, which grows wild in the countries bordering on the Mediterranean. The caprifigs, as the fruit of this tree is called, are worthless except as the breeding and nesting places of a small insect, the fig wasp. This insect is the necessary agent in conveying pollen from the stamens of the caprifig to the pistils of the Smyrna fig, which it penetrates at certain seasons of the year in the effort to lay its eggs. In order to insure *caprification*, as this process is called, the caprifigs are strung by hand on fillets of cord or raffia and hung about on the trees which are to be fertilized. In this case we have an example of a threefold partnership between man, the fig tree, and the wasp, which is necessary to the existence of two of the parties.



FIG. 356. — Female wasps issuing from the galls of caprifigs, in which the eggs are laid.

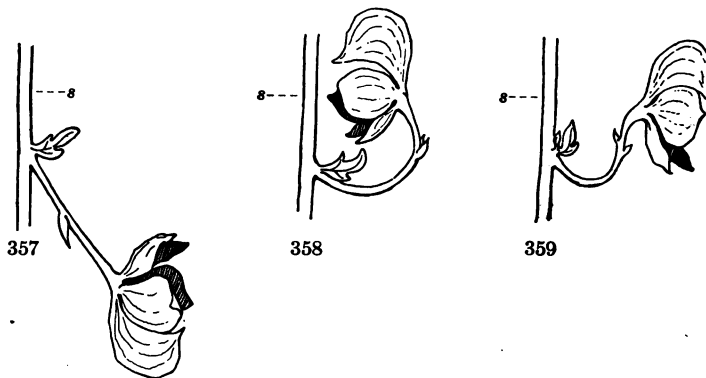
D. PROTECTIVE ADAPTATION

EXPERIMENT 83. ARE THE FLORAL ENVELOPES OF ANY USE? — Carefully remove the calyx and corolla from a young flower bud on a growing plant and see what will happen. Remove them from a flower just unfolding. Mark each by tying a colored thread lightly around the petiole and see if it sets as many seeds, or as good ones, as the unmutilated flowers on the same plant.

EXPERIMENT 84. IS THE POSITION OF A FLOWER ON THE STEM OF ANY IMPORTANCE? — Invert a blossom of pea or sage, and see what parts would come in contact with the body of a visiting insect. How would its chances for pollination be affected? Try to make a flower grow in an inverted position by tying or weighting it down, and watch the effect on seed production.

EXPERIMENT 85. IS THE POSITION OF FLOWERS ON THE STEM INFLUENCED BY LIGHT? — Place a potted plant with expanding flower buds near a window so that the light will reach it from one side only, and notice the position of the buds. After a day or two reverse the position with regard to light, and watch whether any change of position takes place.

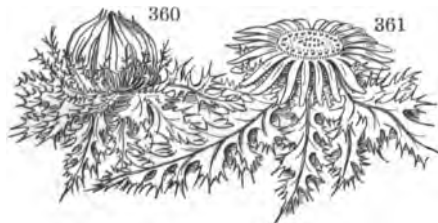
EXPERIMENT 86. IS THE POSITION OF FLOWERS ON THE STEM INFLUENCED BY GEOTROPISM? — Lay a potted plant of lily of the valley, larkspur,



FIGS. 357-359. — Flower of monkshood, showing the changes by which it returns to its original position under the influence of geotropism after the axis of inflorescence, *s*, has been inverted: 357, inverted position; 358, change due to negative geotropism; 359, change due to lateral geotropism.

gladiolus, or *digitalis* in a horizontal position, tie the main stem to keep it from changing its direction of growth, and leave for two or three days in a place where it is lighted equally on all sides. How do the individual flowers behave? What part bends to turn them up? Vary the experi-

ment by turning the pot bottom upwards so that the flowering axis will point downwards. This can be done by inclosing the pot in a bag of strong cheesecloth, with the string tied loosely but firmly around the foot of the stem to prevent the contents from falling out, and suspending the whole bottom upwards. In making these experiments, use flowers that grow in a long cluster, or raceme, and hold the main axis in a vertical position by tying or weighting it down. Watch the behavior of the individual flowers. Arrange another pot containing the same kind of plant, in the



FIGS. 360, 361. — Protection of pollen in the thistle: 360, position at night, or during wet weather; 361, position in sunshine.

same way, and suspend one in a dark place, keeping the other in the light. Does the same movement take place in both? Is it in response to light, or to gravity?

280. Means of protection. — Where plants have adapted themselves to insect polli-

nation, it is, of course, important to shut out intruders that would not make good carriers. In general, small, creeping things, like ants and plant lice, are not such efficient pollen bearers as winged insects, and hence the various devices, such as hairs, scales, and constrictions, at the throat of the corolla, by means of which their access to the pollen is prohibited. To this class of adaptations belong the hairy filaments of the spiderwort, the sticky ring about the peduncles of the catchfly, the swollen lips of the snapdragon, the scales or hairs in the throat of the hound's-tongue, the velvet petals



FIGS. 362, 363. — A bell flower: 362, position in daylight; 363, position at night, or during wet weather.

of the partridge berry, and the recurved edges of corollas like those of the morning-glory and tobacco, over which small crawling insects cannot easily climb.

Of flowers that are pollinated by night moths, some close during the day, as the four-o'clock and the evening primrose; and *vice versa*, the morning-glory, dandelion, and dayflower (*Commelina*) unfold their beauties only in the sunlight. For similar reasons, night-blooming flowers are generally white or very light-colored, and shed their fragrance only after sunset. A nodding position is assumed by many flowers at night, or during a shower, to keep the pollen from being injured by dew or rain.

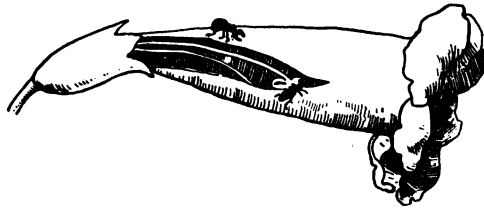


FIG. 364. — A flower of the trumpet vine (*Tecoma radicans*) adapted to pollination by humming birds and humming bird moths, which has been pierced by bees or wasps for honey.

281. Insect depredators. — The secretion of honey by flowers is a very common means of

attracting insect visitors, and various adaptations, such as spurs, sacs, and pockets, are found for protecting it against pillage by unwelcome intruders. In general, plants that have very long, tubular corollas, like the trumpet



FIG. 365. — Head of the swordbill, a bird adapted to feeding on nectar from long, tubular corollas.

honeysuckle (*Lonicera sempervirens*) and the trumpet vine, are reserving their sweets for humming birds and long-tongued moths and butterflies. This protective arrangement is not always successful, however, against insect depredators, for it is not uncommon to find such corollas with a hole in the tube near the base, made by thieving wasps and bumblebees, which by this means get at the honey without paying their due tribute of pollen.

Practical Questions

1. Of what use is the brilliant coloring of the camellia? The large flowers of the magnolia? The perfume of the rose and the violet? The fetid odor of the ailanthus? (277; Exps. 81, 82.)
2. Are the tastes of insects in regard to odors always the same as ours? (Exp. 81.)
3. Have flowers any economic value except for decorative purposes?
4. Can you name any that are used as food or beverages? Any that furnish spices and flavorings? Drugs, medicines, or dyes?
5. What commercial food product is obtained almost entirely from flowers?
6. Name some of the flowers that are most valued by the beekeeper.
7. Mention another important industry that is entirely dependent on flowers.
8. Name some of the flowers that are most important to the perfumer.
9. Why do the seeds of fruit trees so seldom produce offspring true to the stock? (256, 257, 271, 277.)
10. Would you place a beehive near a field of buckwheat? Of clover? Near a strawberry bed? In a peach orchard? Near a fig tree? Under a grape arbor?
11. Why are very conspicuous flowers, like the camellia, hollyhock, and pelargoniums, so frequently without odor?
12. Why is the wallflower "sweetest by night"? (280.)
13. What advantage can flowers like the morning-glory gain by their early closing? (280.)
14. Of what use to the cotton plant, Japan honeysuckle, and hibiscus is the change of color their blossoms undergo a few hours after opening? (277, 278, 280.)
15. Why does the Japan honeysuckle, which has run wild so abundantly in many parts of our country, produce so few berries? (278, 280.)
16. If the trumpet vine grows in your neighborhood, examine a number of corollas and account for the dead ants found in them. Account also for the large hole (sometimes three quarters of an inch in diameter) often found near the base of the tube. (281.)
17. Do you see any connection between the greater freshness and beauty of flowers early in the morning, and the activity of bees, birds, and butterflies at that time?
18. The flowers most frequented by humming birds are the trumpet honeysuckle, cardinal flower, trumpet vine, horsemint (*Monarda*), wild columbine, canna, fuchsia, etc.; what inference would you draw from this as to their color preferences?

Field Work

1. The ecology of the flower is so suggestive a subject and so peculiarly appropriate to outdoor work that it seems hardly necessary to point out the many attractive fields of inquiry it opens to the student of nature. In this way alone can experiments in insect pollination be carried on to the best advantage. Try the effect of enveloping buds of various kinds in gauze so as to exclude the visits of insects, and note the result as to the production of fruit and seed. Envelop a cluster of milkweed blossoms in this way and notice how much longer the flowers so protected continue in bloom than do the others; why is this? Try the same experiment upon the blooms of cotton and hibiscus, if you live where they grow, and see whether the characteristic change in color occurs in flowers from which insects have been excluded, and whether good seed pods are produced by them. Try the effect upon fruit production of excluding insects from clusters of apple, pear, and peach blossoms.

2. Make a list of all the outdoor plants, both wild and cultivated, that are found blooming in your neighborhood, keeping a record of the earliest specimens of each as you find them. The best way is to keep a sort of daily calendar, and at the end of each month give a summary of the species found in bloom during that period. In this way a fairly complete annual record of the flowering time of the different plants for that vicinity will be obtained. The record should be kept up the whole year round. Don't stop in winter, but go straight on through the coldest as well as the hottest season, and you will make some surprising discoveries, especially if the record is continued year after year. Give the common name of each plant, adding the botanical one if you know it. Any facts that you may know or may discover in regard to particular plants, such as their medicinal or other uses, their poisonous or edible properties, the insects that visit them, and in the case of weeds, their origin and introduction, will greatly enhance the interest and value of the record.

CHAPTER VIII. FRUITS

I. HORTICULTURAL AND BOTANICAL FRUITS

MATERIAL. — Green ears of corn or wheat, fresh pods of beans, young fruits of apple, grape, tomato, melon, buckeye, chestnut, or pecan. A young fruiting stem of squash, gourd, or tomato.

APPLIANCES. — Coloring fluid, glasses of water, a piece of cardboard, tin-foil, vaseline.

EXPERIMENT 87. WHERE DO THE FOOD SUBSTANCES CONTAINED IN FRUITS COME FROM? — Apply your food tests to the pulp of a young apple, squash, bean pod, chestnut, buckeye, or a "green" ear of corn or wheat, and see what it contains. Test the stem and roots of a plant of the same kind in the same way. Do you find the same foods in them? Where is the food stored?

EXPERIMENT 88. THROUGH WHAT PARTS OF THE STEM AND FRUIT DO WATER AND NOURISHMENT TRAVEL TO THE SEED? — Cut a young squash or cucumber from the vine, leaving stem enough to insert by its cut end in a glass of eosin solution. Leave for two or three days, then make a vertical section through the stem and fruit. What course has the liquid followed? Can you trace some of it into each seed? Do you see now a use for the seed stalk and the rhaphe?

EXPERIMENT 89. DOES THE SURFACE OF FRUITS GIVE OFF WATER BY TRANSPIRATION? — Try Exp. 59, using in place of leaves a young squash, eggplant, or a bunch of grapes, and after a day or two notice whether any moisture has been given off. If the fruit skin gives off moisture, it is natural to expect that it would be provided with stomata, like other transpiring organs. To find out whether this is so, place a thin piece of the outer epidermis of a grape, tomato, plum, or apple under the microscope. Do you find stomata on any of them? Do you see anything else? Try the skin of an apple, and compare the corky dots you find there with those on the bark of a young dicotyl stem (118) and decide what they are.

EXPERIMENT 90. WILL FRUITS RIPEN WELL IN THE ABSENCE OF LIGHT AND AIR? — Envelop a number of immature fruits in bags of dark cloth or paper so that no light can reach them. Keep a number of others well coated with oil or vaseline, and watch. Do the fruits so treated mature as quickly or develop as fully as those of the same kind left untreated?

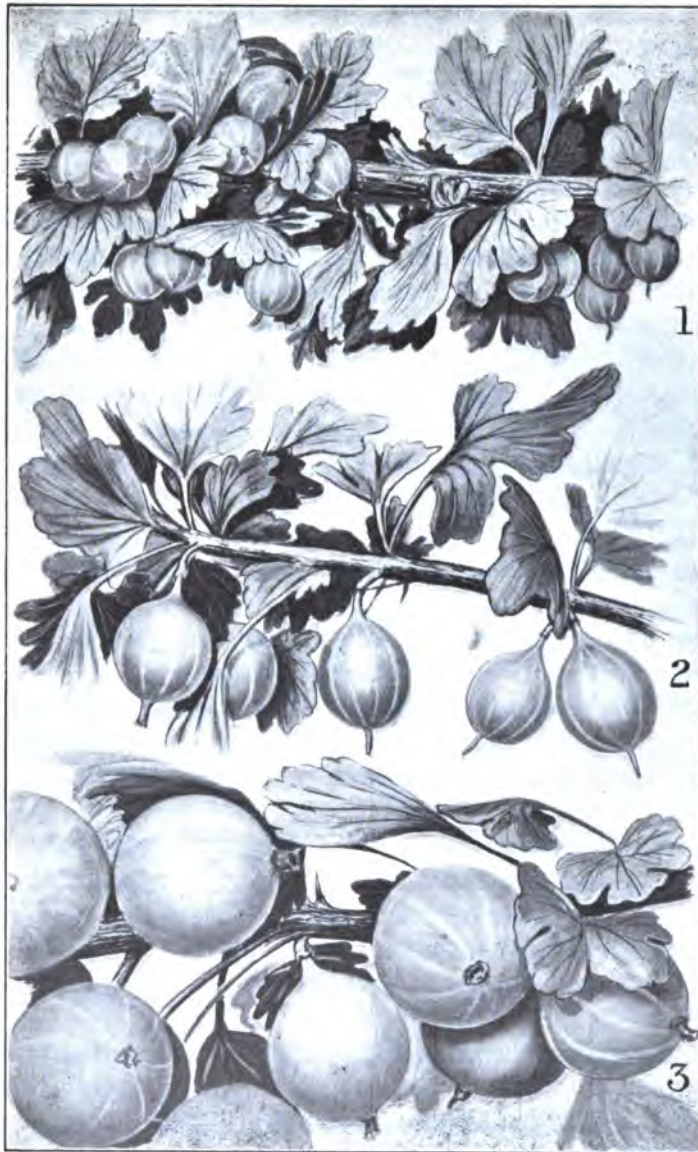


PLATE 12. — The improvement of fruits by cultivation and selection: 1, the common wild gooseberry; 2, Houghton gooseberry, seedling of the wild form; 3, Downing gooseberry, seedling of the Houghton. (All natural size, adapted from Bailey.)

EXPERIMENT 91. WHAT IS THE USE OF THE RIND TO THE FRUIT? — Select two apples of equal size, peel one, and weigh both. After 12 to 24 hours, weigh them again. Which shows the greater loss in weight? Leave peeled and unpeeled fruits in an exposed place and see which is the more readily attacked by insects. Which decays the sooner? What are some of the uses of the rind?

282. What is a fruit? — Horticulturally and commercially the distinction between a fruit and a vegetable depends very much upon the use we make of it — whether as food, or as a mere gratification of the palate. Broadly speaking, those fruits that are lacking in sugar, as the tomato and cucumber, are classed as vegetables. Botanically, a fruit is any ripened seed vessel, or ovary, with such connected parts as may have become incorporated with it; and hence, to the botanist, a boll of cotton, a tickseed, or a cocklebur is just as much a fruit as a peach or a watermelon.

283. Classification of fruits. — For convenience of description, fruits are classed as:

(a) Dry or fleshy, according as they have a more or less hard and bony, or soft and fleshy, texture.

(b) Dehiscent, or indehiscent, according as they open at maturity in a regular way to discharge their seed, or remain closed until the covering wears away or is burst by the germinating embryo.

Fleshy fruits are very seldom dehiscent, though some few, as the balsam apple and the chayote, or one-seeded squash, discharge their seed when mature. The banana and some other fleshy fruits, when peeled, separate along regular lines, and in this respect behave very much as if they were fleshy pods.

284. When is a fruit ripe? — A fruit is ripe horticulturally, when it is good to eat; it is ripe botanically, when it has set its seed. Many of our choicest table fruits, such as the pineapple, banana, and most varieties of fig, seldom are botanically ripe, since they rarely produce perfect seeds.

It is the constant effort of the horticulturist to develop

those parts of a plant that are useful to man, while in a state of nature the plant seeks to develop such parts as best serve its own purpose in the struggle for existence. The plants most useful to man have, as a general thing, been subjected to a long course of artificial breeding and selection. They are forced developments, often monstrosities, from the plant's point of view, if we could conceive of it as capable of having an opinion. Nature is continually striving to reclaim them; and if left to themselves, they must either obey "the call of the wild," or die out.

285. Seedless fruits and vegetables.—As the seed is the most important thing to the plant, the edible parts in wild fruits are, as a rule, subsidiary to its development. In a state of nature, fruits will generally wither and drop from the stem, if for any reason they have become incapable of perfecting their

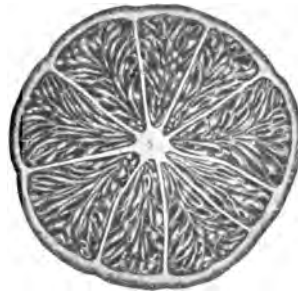


FIG. 366.—A seedless citrange, hybrid between the orange and the lemon.

seed. It is only in a few kinds, limited to those which can successfully propagate themselves by other means, that the production of seed does not take place. Among cultivated species, however, where propagation is carefully provided for by man, the seed is of less importance, and sterile varieties that might soon die out under natural conditions, continue their existence indefinitely under his fostering hand. The seeds of edible fruits are, as a general thing, both indigestible and unpalatable (21), and hence the efforts of the horticulturist are directed largely to getting rid of them, or to very greatly reducing their size and number in proportion to the edible parts.

286. How seedless fruits arise.—The perfecting of seed requires a great consumption of food and energy on the part of the plant, and when it is led, for any reason, to expend an unusual amount of force in some other function,—as

for instance, in producing tubers or in growing bulbs, — it is apt to bear few seeds and to depend more or less completely upon other methods of reproduction.

Among cultivated plants, selection on the part of man, whether conscious or unconscious, has perhaps contributed more than any other cause to bring about the same result. To this agency is probably due the development of our common domestic fig, of which over four hundred varieties that mature fruits without fertilization are cultivated in the United States alone. The fig was one of the earliest fruits known to cultivation; and the early navigators, ignorant of the processes of fertilization, would naturally, in choosing specimens to carry home with them, select only fruit-bearing trees. Such of these as matured fruits would be preserved and propagated, until, by repeated selection, hundreds of edible varieties have been developed that ripen fruits without caprification (279).

287. The use of the fruit to the plant. — The object of the fruit is to furnish protection to the seeds during their period of development and inactivity, and to aid in various ways the work of dispersal. It probably takes part also in digesting and diffusing nourishment for the use of the developing seeds. It has been shown in previous chapters that plants, almost without exception, are in the habit of storing up food in various ways as a provision for fruiting. That a large portion of the stored nourishment is used up in the performance of this function is proved by its disappearance from those parts — for example, from fleshy roots, such as beets and turnips, after they have “gone to seed.”

Practical Questions

1. What is the use of the down on the peach? The bloom of the plum and grape? [202, (1); Exp. 91.]
2. Why are apples, pears, plums, and other fleshy fruits nearly always rosier on one side than on the other? (Exp. 90.)
3. Can annuals be improved in any other way than by seed selection?
4. Would a seedless annual be perpetuated under natural conditions?

5. Why is decrease of moisture and increase of light desirable as the fruiting season approaches? (126, 127; Exp. 90.)

6. Why are turnips, carrots, and other fleshy roots unfit to eat if left over till the plants have seeded? (92, 287.)

II. FLESHY FRUITS

MATERIAL. — A specimen of each of the four principal kinds of fleshy fruits. Examples of the pome are: apple, pear, quince, rose hip, haw; of the berry: grape, tomato, cranberry, currant, gooseberry, lemon; of the pepo: melon, squash, pumpkin; of the drupe: peach, plum, cherry, dogwood. Specimens of the commoner kinds can nearly always be found in the market; if nothing better is available, pickled and dried ones may be used — figs, prunes, dates, raisins, etc.

288. Dissection of a pome fruit. — Examine with a lens the outside of an apple or a pear. Can you make out the lenticels? What difference in color do you notice between the ripe and unripe fruit? What difference in taste? What substance would you judge from this, do ripe fruits contain which green ones do not? Test both kinds for sugar and starch; which contains the more of each? Strictly speaking, sugar and starch are merely different forms



FIG. 367. — Outside of an apple, showing lenticels on the skin.

of the same chemical compound. In ripe fruits the starch has been cooked by the sun and converted into sugar.

With the point of a pencil separate the little dry scales that cover the depression in the center of the fruit at the end opposite the stem. How many of them are there? How does this accord with the plan of the flower as outlined in 229? They are the remains of the sepals, as will be more apparent on comparing them with the larger and more leaflike ones on a hip, which is clearly only the end of the footstalk enlarged

and hollowed out with the calyx sepals at the top. Cut a cross section midway between the stem and the blossom end, and make an enlarged sketch of it. Label the thin, papery

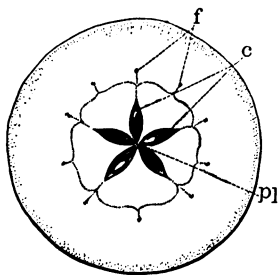


FIG. 368. — Cross section of a pome: *pl*, placenta; *c*, carpels; *f*, fibrovascular bundles.

walls that inclose the seed, *carpels*. How many of them are there, and how many seeds does each contain? The carpels, together with all that portion of the fruit which surrounds and adheres to the ovary, constitute the *pericarp*, or wall of the seed vessel. The fleshy part of the apple is no part of the ovary proper, but consists merely of the receptacle, or end of the foot-stalk, which becomes greatly enlarged and thickened in fruit. Look for a

ring of dots outside the carpels, connected (usually) by a faint scalloped line. How many of these dots are there? How do they compare in number with the carpels? With the remnants of the sepals adhering to the blossom end of the fruit?

Next make a vertical section through a fruit, and sketch, enlarging it sufficiently to show all the parts distinctly. Observe the line of woody fibers outside the carpels, inclosing the core of the apple. Compare this with your cross section; to what does it correspond? Where do these threads originate? Where do they end? Can you make out what they are? (176.) Notice how and where the stem is attached to the fruit. Label the external portion of

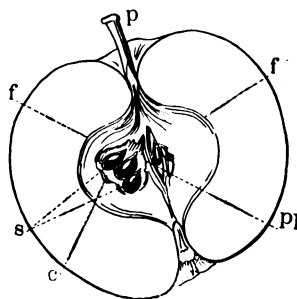
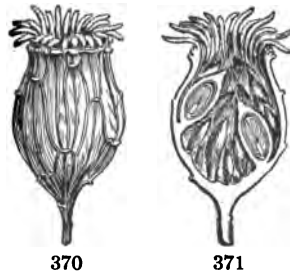


FIG. 369. — Vertical section of a pome: *p*, peduncle; *f*, fibrovascular bundles; *s*, seeds; *pl*, placenta; *c*, carpel.

the stem, *peduncle*; the upper part, from which the fibrovascular bundles branch, the *receptacle*. It is the enlargement of this which forms the fleshy part of the fruit. Try to find out, with the aid of your lens and dissecting pins, the exact

spot at which the seeds are attached to the carpels, and label this point, *placenta*. Notice whether it is in the axis where the carpels all meet at their inner edges, or on the outer side. Observe, also, whether the seed is attached to the placenta by its big or its little end. If you can find a tiny thread that attaches the seed to the carpel, label it, seed stalk. Fruits of this kind are classed, botanically, as *pomes*. Write, from your analysis, a definition of the pome.

289. Modifications of the receptacle.—Compare with the drawings you have made, a haw and a hip. What points of agreement do you see? What differences? Which of the two more closely resembles the typical pome? The receptacle is subject to a variety of modifications, and forms a part of many fruits, for example, the fig, lotus, and calycanthus (Figs. 370, 371); but a fruit is not a pome unless the containing receptacle becomes more or less soft and edible.



FIGS. 370, 371. — Enlarged receptacle of Carolina allspice (*Calycanthus*), containing fruits attached to its inner surface: 370, exterior; 371, vertical section.

290. The pepo, or melon.—Next examine a gourd, cucumber, squash, or any kind of melon, and compare its blossom end with that of the apple or pear. Do you find any remains of a calyx, or other part of the flower? Examine the peduncle and observe how the fruit is attached to it. Can you tell what made the outer epidermis of the rind? Put a small piece under the microscope; do you see any stomata, or lenticels? Cut cross and vertical sections, and sketch them, labeling each part. There may be some difficulty in making out the carpels, for they are not separate and distinct as in the pome, but confluent with the enlarged receptacle, which in these fruits forms the outer portion of the rind, and also with each other at their edges, so as to form one unbroken circle, as if they had all grown together. And this is precisely what

has happened. The placentas are greatly enlarged and modified, and it may be necessary to refer to the diagram, Fig. 372, *c*, in order to make them out. How many locules, or chambers, are there in your specimen? How many

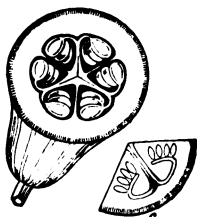


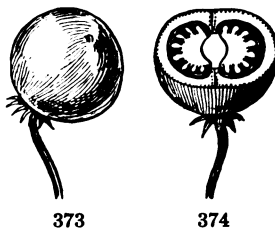
FIG. 372. — Cross section of gourd : *c*, one of the carpels in diagram. (After GRAY.)

placentas? Notice that these are central and double, but extend to the pericarp before dividing so that they appear to be parietal, and twice their real number, which is only three. Are the seeds vertical, as in the apple, or horizontal? Look for the little stalk, or thread, that attaches them to the placenta.

Pepo is the name given by botanists to this kind of fruit. Write in your notebook a proper definition of it, from the specimens examined.

291. The berry. — Examine a tomato, an eggplant, a grape, cranberry, lemon, or orange, in both cross and vertical section, and compare it with the melon and the apple. What differences and resemblances do you find? Cut a cross section, and draw, showing the attachment of the seeds. How many locules are there? Normally the tomato is a two-celled fruit, like the potato berry (Fig. 374), but it has been so modified by cultivation that the original plan is not always easy to distinguish. See if you can make it out. Do the seeds in your specimen appear to be healthy and well developed, or are some of them small and aborted? How do you account for this? (285, 286.) What difference do you notice in color between the ripe and unripe fruit? Write a definition of the berry from the study you have made of it.

Berries are the commonest of all fleshy fruits, and the most variable and difficult to define. In general, any soft, pulpy, or juicy mass, like the grape and tomato, whether one or



FIGS. 373, 374. — A potato berry : 373, exterior ; 374, cross section.

many seeded, inclosed in a containing envelope, whether skin or rind, is a berry. Its typical forms are such fruits as the grape, mistletoe, pokeberry, etc., though such diverse forms as the eggplant, persimmon, red pepper, orange, banana, and pomegranate have been classed as berries; and, in fact, the melon and the pumpkin are only greatly modified kinds of the same fruit. In popular language, any small, round, edible fruit is called a berry. This is a good commercial classification, though not botanically correct.

292. The drupe, or stone fruit. — Examine a section of a green plum, peach, or cherry, before the stone has hardened, and tell from what part it is formed. This stony covering, composed of the inner layer of the pericarp, and enveloping the seed like an outer coat, is the main distinction between the drupe and the berry, but it is not always possible to make out its real nature except by an examination of the young ovary. In a green drupe, before the stone has hardened, its connection with the fleshy part is very evident, and the ripe fruit will answer inquiries if we know how to put them. Open the stone, and the seed will be exposed with its own coverings inside. When a stone has more than one kernel,—for instance, an almond or peach stone,—the stone is not a seed coat, but the hardened inner wall of a seed vessel or ovary; for a seed coat can never contain more than one seed, any more than the same skin can contain more than one animal.



FIG. 375. — Vertical section of a drupe. (After GRAY.)

All the fruits considered in this section belong to the fleshy class. These form the bulk of the fruits sold in the market, and are of special importance to the horticulturist.

Practical Questions

1. Is the tomato horticulturally a fruit or a vegetable? the squash? eggplant? cranberry? olive? elderberry? pepper? date? maypop? crab apple? black haw? To what class does each belong? (283, 288-292.)

2. Of what use to the plant is the hard stone of the drupe? (21.)
3. Is the pulp of fleshy fruits agreeable to the taste before they are ripe? After? What advantage is this to the plant? (21.)
4. Are the seeds of edible fruits, as a general thing, digestible or agreeable to the palate?
5. Is this an advantage to man? To the plant? (21, 284, 285.)
6. What are the most common fleshy fruits in autumn?
7. With what vegetative parts of the plant does the skin of many fruits present correspondences? Are these such as to indicate homology, or analogy only, between them? (100, 118, 288, 289; Exp. 89.)
8. Name six of the most watery fruits that grow in your neighborhood.
9. Under what conditions as to soil, heat, moisture, etc., does each thrive best?
10. Would a gardener act wisely to infer that because a fruit contains a great deal of water it should be planted in a very wet place?
11. Which contains more water, the fruit or the leaves of the apple?
12. Why does not the fruit, when separated from the tree, wither as quickly as do the leaves? (Exp. 91.)

III. DRY FRUITS

MATERIAL. — Some easily attainable specimens of dry fruits are (1) nuts: acorn, hickory nut, walnut, chestnut, pecan, filbert; (2) pods: pea and bean pods, capsules of larkspur, milkweed, jimson weed, cotton; (3) grains: corn, wheat, oats, rice; (4) akene: sunflower, thistle, dandelion, buckwheat, clematis.

293. Importance of dry fruits. — Dry fruits are not in general so conspicuous or so attractive as fleshy ones, but on account of their great number and variety they offer a wide field for study. They are also of great interest from an economic point of view: (1) because they include the cereal grains that furnish so large a portion of our food, and (2) because the greater part of the troublesome weeds that infest our crops are scattered by fruits of this class.

294. Indehiscent fruits. — These kinds are so simple that it will not be necessary to give much time to them. Compare an acorn, a chestnut, or a filbert with a ripe bean pod or with a capsule of morning-glory. Try to open each with your fingers; which *dehisces*, or opens, the more readily? Which is indehiscent, having no regular way of opening? How many

seeds or kernels do you find in the dehiscent pod? How many in the indehiscent one? Would it be of any advantage for a one-seeded pod to open? Remove the kernel from the indehiscent fruit; has it any covering besides the shell? Which is the pericarp, and which the seed coat?

295. The nut is easily recognized by its hard, bony covering, containing usually, when mature, a single large seed that fills the interior. Care should be taken not to confound with true nuts, large bony seeds, like those of the buckeye, horse-



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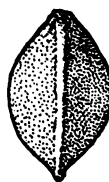
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FIGS. 376, 377. — Nut of the pecan tree: 376, exterior; 377, cross section.

FIGS. 378, 379. — Nutlike seeds: 378, horse-chestnut; 379, seed of the fetid sterculia.

chestnut, date, and the Brazil nut sold in the markets. In the true nut, the hard covering is the seed vessel, or pericarp, and not a part of the seed itself, though it often adheres to it so closely as to seem so. In bony seeds, like those of the horse-chestnut and persimmon, the hard covering is the outer seed coat. The distinction is not always easy to make out unless the seed can be examined while still attached to the placenta of the fruit.

296. The akene, of which we have examples in the tailed fruit of the clematis, the tiny pits on the strawberry, and the so-called seeds of the thistle, dandelion, and sunflower, is a small, dry, one-seeded, indehiscent fruit, so like a naked seed that it is generally taken for one by persons not acquainted with botany. It is the



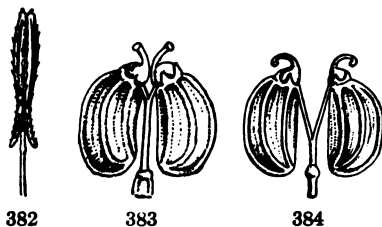
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FIGS. 380, 381. — Akenes (magnified): 380, of buckwheat; 381, of cinquefoil.

commonest of all fruits, and there are so many kinds that special names have been applied to some of the most marked



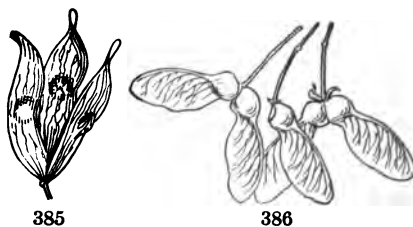
Figs. 382-384. — Cremocarps, fruits of the parsley family.

varieties. The akene of the composite family may generally be known by the various appendages in the form of scales, hooks, hairs, or chaff, that crown it (Figs. 309-314). The fruits of the parsley family are merely a sort of double akene attached by the inner face

to a slender stalk from which it separates at maturity.

The *samara*, or key fruit, is an akene provided with a wing to aid in its dispersion by the wind. The maple, ash, and elm furnish familiar examples.

297. The grain, so familiar to us in all kinds of grasses, is economically the most important of all fruits. It is popularly



Figs. 385, 386. — Samaras: 385, ailanthus; 386, maple.

classed as a seed, and for practical purposes may be treated as such, but it is really a modification of the akene in which the seed coats have so completely fused with the pericarp



Figs. 387, 388. — Grain of broom corn millet with husks on: 387, front view; 388, back view.

that they can no longer be distinguished as separate organs. Peel the husk from a grain of corn that has been soaked for twenty-four hours, and you will find the contents exposed without any covering; remove the shell of an acorn or a hickory nut, and the seed will still be enveloped by its own coats. Would it be of any

advantage for the seed of an indehiscent fruit, like a grain of corn or oats, to have a separate special covering of its own?

298. Dehiscent fruits. — *Pod*, or *capsule*, is the general name applied to all dehiscent fruits. The simplest possible kind of pod is the *follicle*, composed of a



FIG. 389. — Follicle of milkweed.

single carpel, like those of the larkspur, milkweed, and marsh marigold, and may be regarded as a modified leaf. Examine one of these pods and you will find that it splits down one side, which corresponds to the edges of the leaf brought together and turned inward to form a placenta for the attachment of the seed. This line of union is called a “suture,” from a Latin word meaning a “seam.”

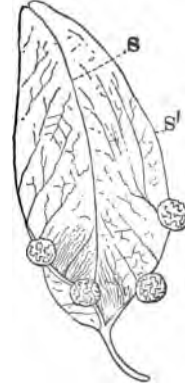
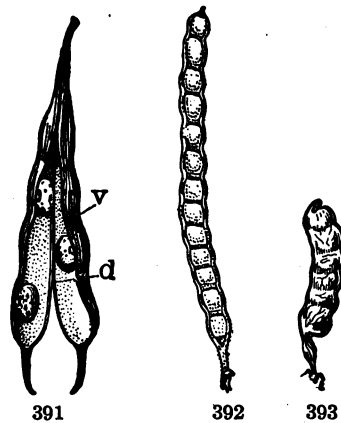


FIG. 390. — Leaf-like follicle of Japan varnish tree: *S*, outer (dorsal) suture; *S'*, inner (ventral) suture.

299. The legume. — Get a pod of any kind of bean or pea, and observe that it differs from the follicle in having two sutures or lines of dehiscence. One of these runs along the back of the carpel and corresponds to the midrib of the leaf; the other, corresponding to the united edges of the carpellary leaf, always turns inward, toward the axis of the flower, and forms the placenta.

The beggar-ticks, so unpleasantly familiar to most of us, are merely a kind of legume constricted between the seeds and breaking up into separate joints at maturity. What kind of



FIGS. 391-393. — Legumes: 391, legume of bean: *v*, ventral suture; *d*, dorsal suture; 392, constricted legume of senna (*Cassia Nelsonia*); 393, legume of a pea, with partially constricted pod.



FIG. 394. — Loment of beggar-ticks.

indehiscent fruits do the joints become when separated? (296.)

300. Compound or syncarpous pods.

— The carpellary leaves may unite either by their open edges, as if a whorl like that represented in Fig. 194 were to grow together by the margins (Fig. 395); or each may first roll itself into a simple follicle like the lark-



FIG. 395. — Cross section of one-celled syncarpous capsule of frost-weed, with parietal placentæ. (After GRAY.)



FIG. 396. — Follicles of larkspur borne on the same torus, but distinct.

spur and columbine (Fig. 396), and then a number of these may unite by their ventral sutures into a single syncarpous capsule, with as many locules as there are carpels



397

FIG. 397. — Pods of *Echeveria*, contiguous, but distinct.



398

FIG. 398. — Capsule of *Colchicum*, with carpels united into a syncarpous pod.



399

FIG. 399. — Capsule of corn cockle, with free central placenta.

(Fig. 398). The seed-bearing sutures being all brought together in the center, the placenta becomes *central* and *axial*. In the first case (Fig. 395) the open carpels form a one-chambered capsule, though the placentas sometimes project, as in the cotton, so far as to produce the effect of true partitions with a central axial placenta. In capsules with

only one compartment, the number of carpels can generally be determined by the number of sutures or of placentas.

Practical Questions

1. To what class of fruits does each of the following belong — rice; beggar-ticks; poppy; peanut; jimson weed; chinquapin; caraway?

2. Is the coconut, as usually sold in the market, a fruit or a seed?

Suggestion: carefully examine the "eyes," from without and from within; if you can get a specimen with the husk on, it will help to a decision.

3. Can you name any syncarpous, or compound capsule, that is single-seeded?

4. Can you name any indehiscent fruit that has normally more than one seed?

5. Give a reason for the difference. (23.)

6. Name the weeds of your neighborhood that are most troublesome on account of their adhesive fruits.

7. Do these fruits belong, as a rule, to the dehiscent or to the indehiscent class?

8. Give a reason for the difference, if any is noted. (23.)

IV. ACCESSORY, AGGREGATE, AND MULTIPLE FRUITS

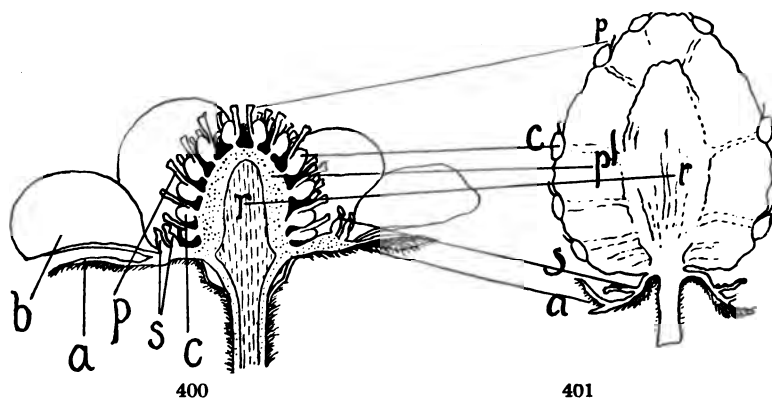
MATERIAL. — For autumn and winter, examples of accessory fruits are: pineapple, common apple, pear, rose hip; aggregate: magnolia, tulip tree, wild cucumber, sweet flag (*Calamus*); multiple: osage orange, sweet gum balls, pine cones, figs, fresh or dried.

For spring and summer, examples of accessory fruits are: raspberry, strawberry, squash, cucumber; aggregate: strawberry, blackberry, Jack-in-the-pulpit; multiple: fig, mulberry. Most of those named will be found to belong to more than one class; the strawberry, for instance, is both accessory and aggregate; the fig and pineapple, accessory and multiple.

301. Besides the varieties already named, all fruits, whether fleshy or dry, may be simple, accessory, aggregate, or collective. Fruits of the first kind need no explanation; they consist merely of a single ripened ovary,

whether of one or more carpels, as the peach, cherry, bean, and lemon.

302. Accessory fruits are so called because some other part than the seed vessel, or ovary proper, is coherent with, or accessory to it, in forming the fruit, as in the apple and the hip. The accessory part may consist of any organ, but is more frequently the calyx or the receptacle. In the strawberry, the little hard bodies, usually called seeds, that dot the surface are the true fruits (akenes). A vertical section through the center will show the edible part to consist



FIGS. 400, 401. — Vertical sections showing the relation between a strawberry flower and fruit: 400, the flower; 401, the fruit developed from it. The corresponding parts are indicated by connecting lines; *r*, receptacle; *a*, sepal; *b*, petal; *s*, stamens; *c*, carpel (akene in fruit); *p*, style of the pistil; *pl*, pulp of the fruit.

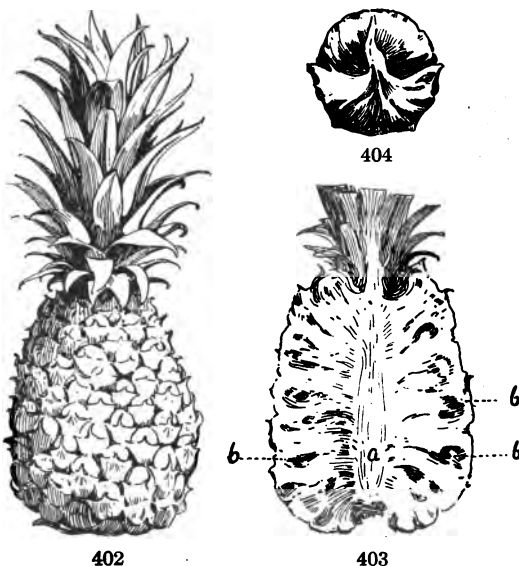
wholly of the enlarged receptacle. In the pineapple, the edible stalk may be traced through a mass of flowers whose seed vessels have become enlarged and ripened into fruits.

303. Aggregate fruits. — Some accessory fruits, the strawberry and blackberry for example, are, at the same time, aggregate; that is, they are composed of a number of separate individual fruits produced from a single flower. The cone of the magnolia and of the tulip tree are aggregate fruits; can you name any others?

304. Collective, or multiple, fruits. — The pineapple is an example of both an accessory and a multiple fruit, being composed of the ripened ovaries of a number of separate flowers that have become more or less coherent. The osage orange, sweet gum balls, fig, and mulberry are other examples of this class.

305. Dissection of a multiple fruit.

— Get one of the dried figs sold by the grocers. Look at the small end where the skin originates; of what part is it a modification? (289.) Can you think of a reason for this



FIGS. 402-404. — Multiple fruit of the pineapple: 402, external view of a ripe fruit, showing the prolonged receptacle growing into a new plant above, and the scaly bracted covering below; 403, vertical section through the axis of a fruit, showing *a*, the receptacle, with *b, b*, the fleshy ovaries cohering around it and forming the edible part of the fruit; 404, a single "eye" or scale, somewhat reduced, showing the scaly bract from the axil of which the (generally) abortive flower originates.

curious, urnlike enlargement of the receptacle? Is there anything about the fig, for instance, that renders it peculiarly liable to be preyed upon by birds and insects? Could any but a very small insect get through the eye without injuring the fruit? Could it free itself from the sticky mass inside and get out again without difficulty? Would you judge from this that the caprification of the fig is easily effected (279), even when the fig wasp is present? Can you now account for the fact that over four hundred varieties of cultivated figs ripen their fruit without fertilization?

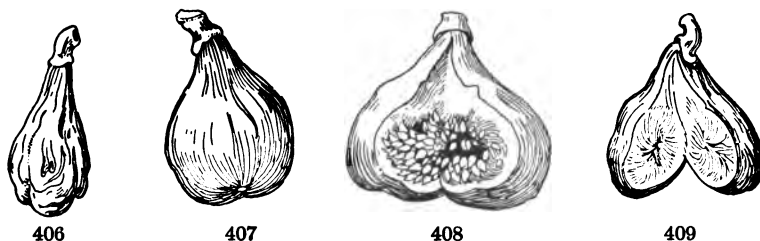
Open your specimen and examine the contents; what do you find? From a dried specimen it will hardly be practicable to make out clearly that the pulp of the fig consists of hundreds of tiny pistillate blossoms that line the inner face of the



FIG. 405. — Vertical section of a fig, showing the minute flowers inside the closed receptacle.

receptacle. The little grains usually taken for seeds are really small akenes — the ripened ovaries of flowers that have been pollinated from the caprifig (279, 286). Crush one gently and examine with a lens, or under a low power of the microscope. It is these “botanically”

ripe fruits (284) that give to the dried figs of commerce their plumpness and their pleasant, nutty flavor. Why are our native American figs lacking in these qualities (279)? Could this defect be remedied? Do you know of any efforts being made in that direction by American cultivators?



FIGS. 406-409. — Non capricifig and capricifig figs: 406, outside appearance of non capricifig fig; 407, outside appearance of capricifig fig; 408, interior of capricifig fig; 409, interior of non capricifig fig.

306. Fruit clusters. — Be careful not to confound aggregate and collective fruits with mere clusters, like a bunch of grapes or of sumac berries. The distinction is not always easy to make out. The clump of akenes that make up a dandelion ball, for instance, though held on a common receptacle, like the mulberry and other collective fruits, have so little connection with each other, and separate so completely at maturity, as to partake more of the nature of a

cluster than of a collective fruit. The same is true of the clump of tailed akenes that make up the fruit of the clematis. Though the product of a single flower and thus technically an aggregate fruit, they are really only a compact head or cluster. Some degree of cohesion is necessary to constitute a cluster of matured ovaries into an aggregate or a multiple fruit.

307. The individual fruits that make up the various kinds just described may belong to any of the classes mentioned in the two preceding sections: those of the blackberry, for instance, are drupes; of the strawberry, akenes; of the sweet gum, capsules.

Practical Questions

1. To what class of fruits would you refer the following: a banana; a tickseed; a dewberry; a cocklebur; a string bean; a watermelon; a cantaloupe; a pomegranate; a black haw; a dogwood berry; a red pepper?
2. Tell which of the following are aggregate or multiple fruits, and which are fruit clusters: an ear of corn; of wheat; a buttonwood or a sycamore ball; a hop; a dewberry; a pine cone; a prickly pear. (303, 304, 306.)
3. Tell the nature of the individual fruits composing the different combinations mentioned in the last question.
4. Can you suggest any advantage that might accrue to a species from having its fruits clustered or compound? (21, 23, 24, 287.)

Field Work

1. Study the various edible fruits of your neighborhood with regard to their means of dissemination and protection. Consider the object of the protective adaptations in each case, whether against heat, cold, moisture, animals, etc. Notice the color of the different kinds, and trace its significance; for example, the bright red of the holly, the dull color of muscadine, black haw, and wild smilax. Account for the prevalence of red among autumn fruits. Notice the position of the fruit on the bough and explain its object; as, for instance, the clustering of dogwood at the end of the twig, the pendent position of grapes and honey locusts. Observe

the relation between the color and size of fruits and their grouping. What advantage is it for sumac and bird haws to be gathered in large clusters?

2. Compare wild with cultivated fruits and notice in what respects man has altered the latter for his own benefit. Note, for instance, the difference between cultivated apples and the wild crab, between the cultivated grains and wild grasses. Observe the great number of varieties of each kind in cultivation and try to account for it.

3. Notice the situations in which different kinds of fruits grow, whether hot, dry, moist, windy, or sheltered, and how they are affected by their surroundings. For example, account for the difference between blackberries growing on a dry hillside, and those in moist land along the borders of a stream. Give the conclusions drawn from your observations in each case.

4. Notice what animals feed upon the different kinds, and whether their visits are harmful or beneficial. Consider in what respects the interests of the plant itself, the interests of man, and the interests of other animals may clash or coincide. Examine the vegetation along the hedgerows and borders of fields and old fences. Notice the kind of plants that compose it — sumac, sassafras, cedars, cat brier, etc. The list will be slightly different for different localities, but this will not alter the general conclusion. What kinds of fruits and seeds do these shrubs produce? What kinds of living creatures frequent hedgerows and feed upon the seeds of such plants? Do you see any relation between these facts and one of the modes of seed dispersal?

5. Classify all the fruits you have collected during your walk, under their proper heads, as fleshy or dry, dehiscent or indehiscent, simple, accessory, aggregate, collective. Be careful to distinguish between compact clusters, like the heads of clematis or buttonwood, and truly compound fruits.

CHAPTER IX. THE RESPONSE OF THE PLANT TO ITS SURROUNDINGS

I. ECOLOGICAL FACTORS

MATERIAL. — A number of small flowerpots filled with soils of as many different kinds as can be found in the neighborhood.

308. Definition. — By *ecology* is meant the relation of plants to their surroundings, which may be considered under three general heads: their relations to inanimate nature, to other plants, and to animals. The subject has been touched upon repeatedly in the foregoing pages, and, in fact, it is impossible to treat of any branch of botany without some reference to it. All that was said about the adjustment of leaves for light and moisture, and their adaptations for protection and food storage, about the devices for pollination, and for fruit and seed dispersal, really belong to ecology.

309. Symbiosis. — The relations of plants to animate nature are termed *biological*, and may act in two ways: (1) through the destruction of vegetation by hungry animals and by parasitic and disease-producing organisms; and (2) by associations for mutual benefit, such as are described in section VIII of chapter VII. Associations of this kind are included under the general term *symbiosis*, a word which means "living together." In its broadest sense symbiosis refers to any sort of dependence or intimate organic relation between different kinds of individuals, and so may include the climbing and parasitic habits; but it is usually restricted to cases where the relation is one of mutual benefit. It may exist either between plants of one



PLATE 13.—Showing the quick response of vegetation to surroundings. The upper cut shows the appearance of an irrigation canal in the arid plains region, when first completed; the lower cut, ten years after completion.

kind with those of another, between animals with animals, or between plants and animals, as in the case of the clover and bumblebee, and the yucca and pronuba.

The occurrence of root tubercles on certain of the leguminosæ (63) is a clear case of symbiosis, the microscopic organisms in the tubercles getting their food from the plant and at the same time enabling it to get food for itself from the air in a way that it could not otherwise do.

310. Relations with inanimate nature. — But it is to the relations of plants with inanimate nature, and their grouping into societies under the influence of such conditions, that the term “ecology” is more strictly applied. The external conditions that lead to the grouping are called *ecological factors*. The most important of these are temperature, moisture, soil, light, and air, including the direction and character of the prevailing winds. Each of these factors is complicated with the others and with conditions of its own in a way that often makes it difficult to determine just what effect any one of them may have in the formation of a given plant society.

311. Temperature may be even and steady, like that of most oceanic regions, or it may be subject to sudden caprices and variations, like the “heated terms” and “cold snaps” that afflict our Eastern coast region every few years. It is not the average temperature of a climate, but its extremes, especially of cold, that limit the character of vegetation.

Temperature probably has more influence than any other factor upon the distribution of plants over the globe; but it can have little or no effect in evolving local differences in vegetation, because the temperature of any given locality, except on the sides of high mountains, will ordinarily be the same within a circuit of many miles.

312. Moisture, again, may be of all degrees, from the superabundance of lakes and rivers and standing swamps, to the arid dryness of the desert, and the water may be

still and sluggish, or in rapid motion. It may exist more or less permanently in the atmosphere, as in moist climates like those of England and Ireland, where vegetation is characterized by great verdure; or it may come irregularly in the form of sudden floods, or at fixed intervals, causing an alternation of wet and dry seasons. Moreover, the moisture of the soil or the atmosphere may be impregnated



FIG. 410. — The effect of cold — a Mt. Katahdin bog. (*From Mo. Botanical Garden Rep't.*)

with minerals or gases, which may affect the vegetation independently of the actual amount of water absorbed.

Snow is a form of water which may act in two entirely opposite ways: (1) by keeping the atmospheric precipitation locked up in a solid state and thus bringing about a condition analogous to drought — for example, in arctic deserts and Alpine snow fields; (2) by causing annual floods and overflows when it melts in the spring, as in the Nile and Mississippi valleys.

In cold temperate regions it also influences vegetation

to a considerable extent by covering the warm earth like a blanket during winter, and thus protecting tender seeds and shoots that otherwise would not be able to survive.

313. Light may be of all degrees of intensity, from the blazing sun of the treeless plain to the darkness of caves and cellars where no green thing can exist. Between these extremes are numberless intermediate stages: the dark ravines on the northern side of mountains, the dense shade of beech and hemlock forests, and the light, lacy shadows of the pines,—each characterized by its peculiar form of vegetation. Absence

of light, too, is usually accompanied by a lowering of temperature and a reduction of transpiration, factors which tend to accentuate the difference between sun plants and shade plants, giving to the latter some of the characteristics of



FIG. 411.— Dogwood, a tree tolerant of shade, growing and blooming in a deeply wooded glen.

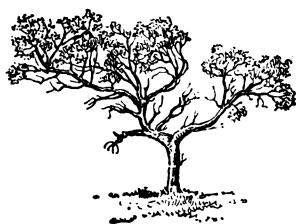


FIG. 412.— A red cedar grown in a barren, wind-beaten situation.

aquatic vegetation. Generally, the tissues of these are thin and delicate, and having no need to guard against excessive transpiration, they wither rapidly when cut or exposed to too great intensity of heat and light.

314. Winds affect vegetation, not only as to the manner of seed distribution and the conveyance of pollen, but directly by increasing transpiration, and necessitating the development of strong holdfasts in plants growing upon mountain sides and in other exposed situations. The nature of the region from which they blow — whether moist,



FIG. 413. — A red cedar grown under normal conditions.

dry, hot, cold, etc.—is also an important factor. In a district open to sea breezes, live oaks, which require a salt atmosphere, may sometimes be found as far as a hundred miles from the coast.

315. Soil.—While water is the most important, soil is perhaps the most interesting of these factors to the farmer, because it is the one that he has it most largely in his power to modify. It is to be viewed under two aspects: first, as to its mechanical properties, whether soft, hard, compact, porous, light, heavy, etc.; secondly, as to its chemical composition and the amount of plant food-materials contained in it. The first can be regulated by tillage and drainage, the second by a proper use of fertilizers.

EXPERIMENT 92. TO SHOW THE INFLUENCE OF SOIL AS AN ECOLOGICAL FACTOR.—Fill a number of small earthen pots with all the different kinds of soil that are to be found in your neighborhood. Keep well moistened and make a list of the plants that appear spontaneously in each. Is there any difference in the kinds produced by different soils? In vigor or abundance of the same or different kinds? Do more seedlings appear in any of the pots than could live if left alone? What becomes of a majority of the seedlings that come up in a state of nature?

After a time, stop watering until all the plants are dead and new ones cease to appear. Notice the rate at which vegetation dies out in each and the kind of plants that can live longest without water. Which of the different soils is capable of sustaining vegetation longest without a fresh supply of moisture? To what quality of the soil is this due? (Exp. 53.)

Practical Questions

1. Is the relation between man and the plants cultivated by him a symbiosis? (309.)
2. Why is it that plants of the same, or closely related species are found in such different localities as the shores of Lake Superior, the top of Mt. Washington, and the Black Mountains in North Carolina? (311, 330.)

3. Which of the five ecological factors mentioned in paragraphs 311-315 has probably most largely influenced their distribution?
4. What is the prevailing character of the soil in your neighborhood?
5. Is your climate moist or dry? Warm or cold?
6. Can you trace any connection between these factors and the prevailing types of vegetation?

II. PLANT ASSOCIATIONS

MATERIAL. — The subject is not well suited to laboratory work, though, if time permits, it is recommended that a detailed study be made of at least one typical hydrophyte, halophyte, and xerophyte plant. Some good examples are: (1) Hydrophyte: pondweed, waterlily, pipewort (*Eriocaulon*), bladderwort, arrowhead (*Sagittaria*); (2) Halophyte: sea lavender, sea rocket, sea lettuce, water hyacinth; (3) Xerophyte: cactus, century plant, pineapple, stonecrop, purslane, lichen.

316. Modes of grouping. — Plants group themselves in their favorite habitats, not according to their botanical relationships, but with regard to the predominance of one or more of the ecological factors that influence their growth. Sometimes one or two species will take practical possession of large areas, like the coarse grasses that spread over certain salt marshes, or the pines that formerly constituted the sole forest growth over extensive regions in North Carolina and Maine. Exclusive growths of this kind over limited areas are sometimes called plant *colonies*, and the individuals composing them belong, as a general thing, to the hardy, pushing sort known as "pioneers," which are among the first to take possession of new soil and force their way into unoccupied territory. But more usually we find a great diversity of forms brought together by their common requirements as to shade, soil, moisture, and other external conditions.

Any well-defined assemblage of plants, whether of one kind or many, originating in such a common response to the same influences, is called a *formation*. These associations are variously classed, according to the nature of their habitat, as salt water, fresh water, sand hill, swamp, bog, river bottom, or such other kinds as their ecological character may

indicate. Local conditions in limited areas may lead to the segregation of smaller and more compact groups called *societies*. This term, however, is used rather loosely, being treated in some works as synonymous with formations, in others as analogous with what have here been defined as colonies.

317. Principles of subdivision. — The mixed associations described in the last paragraph are quite independent of



FIG. 414. — A colony of Alabama primroses (*Erythronium speciosum*).

botanical relationships, and any of the factors named in 310, or others of a different kind, could be made the basis of their classification. They might be grouped, for instance, according to their economic uses, or according to origin, whether native or introduced, as best suited the purpose of the classification in each case. The moisture factor, however, has been generally agreed upon as the one most convenient for ordinary purposes. Upon this principle plants are divided into three great groups: —

Hydrophytes, or water plants, those that require abundant moisture.

Xerophytes, or drought plants, those that have adapted themselves to desert or arid conditions.

Mesophytes, plants that live in conditions intermediate between excessive drought and excessive moisture. To this class belong most of our ordinary cultivated plants and the greater part of the vegetation of the globe.

Halophytes, "salt plants," is a term used to designate a fourth class, based not directly upon the water factor, but upon the presence of a particular mineral in the water or the soil which they can tolerate. They seem to bear a sort of double relation to hydrophytes on the one hand and to xerophytes on the other.

318. Hydrophyte societies. — These embrace a number of forms, from those inhabiting swamps and wet moors, to the submerged vegetation of lakes and rivers. An examination of almost any kind of water plant will show some of the physiological effects of unlimited moisture. Take a piece of pondweed, or other immersed plant, out of the water and notice how completely it collapses. This is because, being buoyed up by the water, it has no need to spend its energies in developing woody tissue. Floating and swimming plants will generally be found to have no root system, or very small ones, because they absorb their nourishment through all parts of the epidermis directly from the medium in which they live. That they may absorb readily, the tissues are apt to be soft and succulent and the walls of the cells composing them

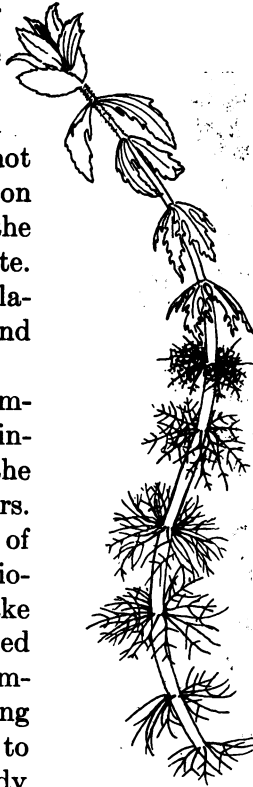


FIG. 415. — A water plant (*Limnophila*), with water leaves and air leaves and transitional forms.

very thin. In some of the pipeworts (*Eriocaulon*), the cells are so large as to be easily seen with the unaided eye. If you can obtain one of these, examine it with a lens and notice how very thin the walls are. Water plants also contain numerous air cavities, and often develop bladders and floats, as in the common blad-



FIG. 417. — A pioneer swamp colony of cattails. (From a photograph by Harry B. Shaw, U.S. Dept. Agr.)

derwort and many seaweeds. The leaves of submerged plants are usually either greatly reduced in size or very much cut and divided, while the ones that rise above water, like those of the water lily, are apt to be large



FIG. 416. — Seaweed (*sargassum*) with bladderlike floats.

and entire, to facilitate floating, and have stomata on their upper surface. Floating plants sometimes form such large colonies as to be a serious menace to navigation. Well-known instances of this are the water hyacinths in the St. John's River, Florida, and the vast formations of swimming gulfweed from which the Sargasso Sea takes its name.

319. Swamp societies. — These include what may be regarded as the amphibious portion of the hydrophyte group. They compose the sedge and cattail bogs, reed jungles, moss and fern thickets, forests of cypress, magnolia, black gum, pine, tamarack, balsam, and

the like. The sedges and cattails are the pioneers of these societies, which tend constantly to encroach upon the water and so prepare the way for the advance of other colonists.

Drawing their nourishment from the loose soil in which they are anchored, and lacking the support of a liquid medium, they develop roots and vascular stems. The roots of plants growing in swamps have difficulty in obtaining proper aëration on account of the water, which shuts off the air from them; hence they are furnished with large air cavities, and the bases of the stems are often greatly enlarged, as in the Ogeechee lime (*Nyssa capitata*) and cypress, to give room for the formation of air passages. The peculiar hollow pro-



FIG. 418. — A Southern cypress swamp, showing on the left the peculiar enlargements for aëration, known as "cypress knees." (From Mo. Botanical Garden Rep't.)

jections known as "cypress knees" are arrangements for aërating the roots of these trees.

320. Xerophyte societies are adapted to conditions the reverse of those affected by hydrophytes. The extreme of these conditions is presented by regions of perennial drought, like our Western arid plains and the great deserts of the interior of Asia and Africa. Under these conditions plants have two problems to solve, — to collect all the moisture they can and to keep it as long as they can. Hence, plants of such regions have a diminished evaporating surface, owing to the absence of foliage and the compacting of their tissues

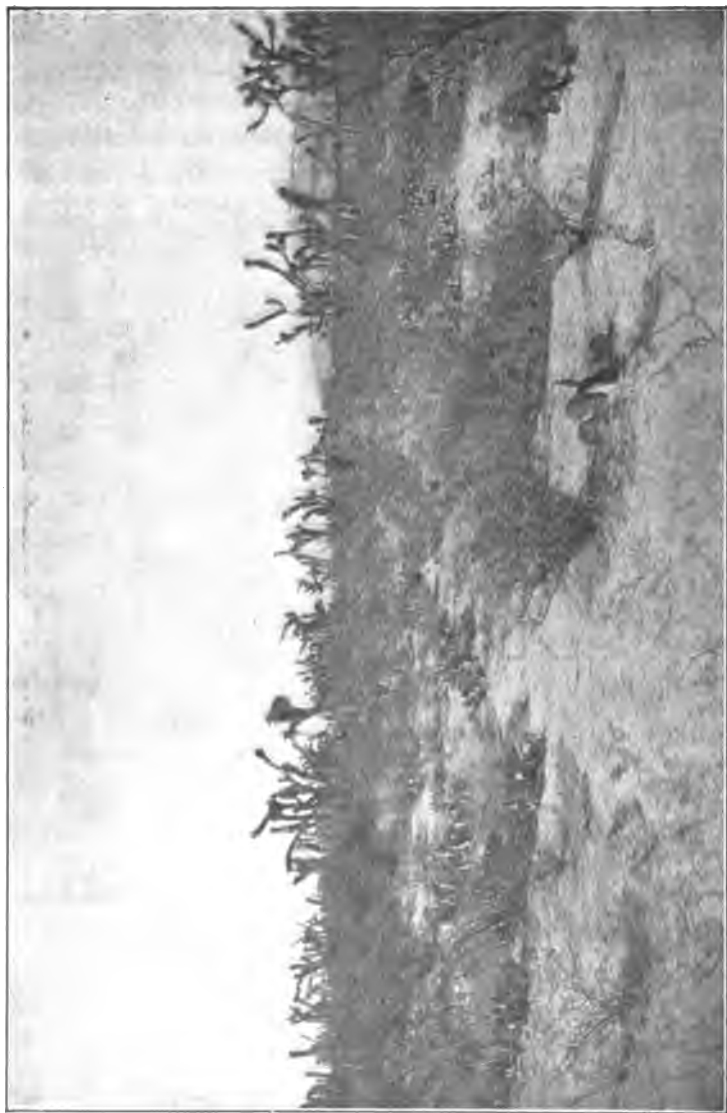


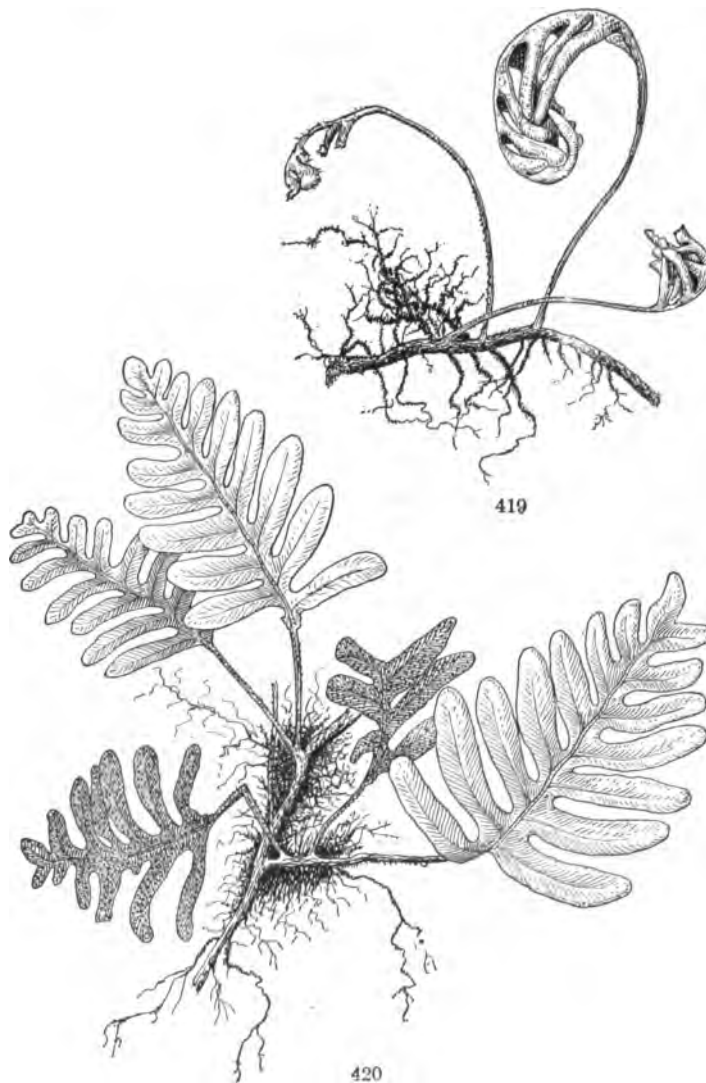
PLATE 14. — A xerophyte formation of yuccas, cacti, and switch plants, near Zacatecas, Mexico.
(From a photograph by Professor F. E. Lloyd.)

into the stem, after the manner of the cactus and prickly euphorbia; or their leaves may become thick and fleshy so as to resist evaporation and retain large amounts of moisture, as in the case of the yucca and century plant. They also frequently develop a thick, hard epidermis, or cover themselves with protective hairs and scales.

The principal types of xerophyte plants are: (1) the lichens, mosses, and saxifrages found on bald rocks and mountain cliffs; (2) sand plants, such as cockspur grass, sand spurry, wiregrass, and the like, inhabiting sea beaches and pine barrens; (3) the sage brush, greasewood, and switch plants of our Western alkali plains; (4) the cactus and yuccas of southern California, Arizona, and Mexico; (5) the acacias, agaves, and hardy "chapparal" thickets of southern Texas and Mexico. The first class are of importance as the pioneers and pathfinders of the xerophyte community. In tropical and polar deserts alike they are the first settlers, and by aiding in the disintegration of rocks and their gradual conversion into soil, they pave the way for the coming of the higher plants, and it may be of man himself.

321. Partial xerophytes. — Plants exposed to periodic and occasional droughts frequently provide against hard times by laying up stores of nourishment in bulbs and rootstocks and retiring underground until the stress is over. This is known as the *geophilous*, or earth-loving, habit. Others, as some of the lichens, and the little resurrection fern (*Polypodium incanum*, Figs. 419, 420), so common on the trunks of oaks and elms in the Southern States, make no resistance, but wither away completely during dry weather, only to waken again to vigorous life with the first shower.

322. Physiological xerophytes. — Plants growing in thin or poor soil, such as that on denuded hillsides, fresh railroad cuts, and newly graded streets, are apt to take on a more or less xerophytic character, even though there may be no lack of moisture. Such soils are called "new" because the mineral elements in them have not been exposed long enough



FIGS. 419, 420. — A resurrection fern : 419, in dry weather ; 420, after a shower.

to have become decomposed and mixed with humus, and the vegetation that first populates them has to do the pioneer work of disintegrating and impregnating the substratum with

humus. For similar reasons the vegetation of sandy bogs and sea beaches, owing to the poverty of the soil in nitrogenous matter, usually develops xerophyte adaptations, even though there may be a superabundance of moisture. Plants growing on high mountain tops and in cold arctic bogs take on the same characteristics (Fig. 410). Such situations are said to be "physiologically dry," because the moisture they have is not in a condition to be readily ab-

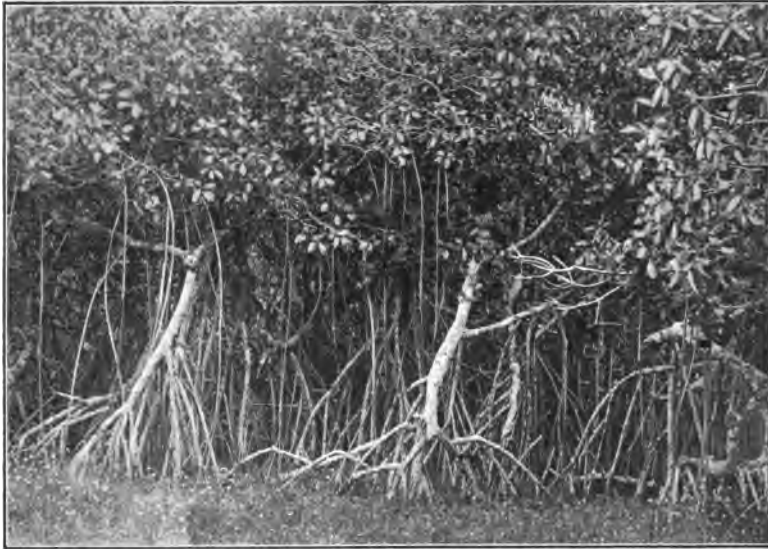


FIG. 421.—A halophyte swamp of mangroves. Notice the tangle of adventitious prop roots assisting in the work of absorption from the brackish marsh soil. (From Mo. Botanical Garden Rep't.)

sorbed. The vegetation of arctic regions suffers more from physiological drought than from cold.

323. Halophytes include plants growing by the seashore and the vegetation around salt springs and lakes and that of alkali deserts. Seaweeds are in a sense halophytes, since they live in salt water, but as they are true aquatic plants and exhibit many of the peculiarities of hydrophytes in their mechanical structure, they are classed with them. The name *halophyte* applies more particularly to land plants

that have adapted themselves to the presence in the soil or in the atmospheric vapor, of certain minerals, popularly known as salts, which cause them to take on many xerophyte characteristics. The reason for this, as was shown in Exp. 39, is because the mixture of salt in the water of the soil increases its density so that it is difficult for the plant to absorb as much as it needs, and thus halophytes are living under "physiologically" xerophyte conditions. If you have ever spent any time at the seashore, you cannot fail to have observed the thick and fleshy habit exhibited by many of the plants growing there, such as the samphire, sea purslane (*Sesuvium*), and sea rocket (*Cakile*). A form of goldenrod found by the seashore has thick, fleshy leaves, and is as hard to dry as some of the fleshy xerophytes.

Another characteristic of desert plants that is common also to seaside vegetation is the frequent occurrence of a thick, hard epidermis, as in the sea lavender and saw grass. The live oaks, trees that love the salt air and never flourish well beyond reach of the sea breezes, have small, thick, hard leaves, very like those of the stunted oaks that grow on the dry hills of California. The presence of spines and hairs, it will be observed, is also very common; *e.g.* the sal-sola, the sea oxeye, and the low primrose (*Oenothera humifusa*). In other cases the leaf blades are so strongly involute or revolute (202) as to make them appear cylindrical. All these, it will be observed, are xerophyte adaptations, and the object in both cases is the same — the conservation of moisture.

324. Mesophytes. — These embrace the great body of plants growing under the ordinary conditions of temperate regions, which may vary from the liberal water supply of low meadows and shady forests to the almost desert barrenness of dusty lanes and gullied, treeless hillsides. The forms and conditions they present are so varied that it would be impracticable to consider them all in a work like this, but they may be summed up under the two general heads of

(1) *open ground* and (2) *woodland*. Under the first are included: (a) all cultivated grounds—fields, meadows, lawns, pastures, and roadsides, with their characteristic shrubs, flowers, and grasses; (b) heaths and plains of northern or alpine regions, with their low, stunted perennials and bright, but fugacious, flowers. Under the second are classed all woods, thickets, and copses, with the shrubs and herbs that form their undergrowth. These may be grouped in three main divisions: (c) mixed forests of maple, ash, oak, hickory, birch, sweet gum, etc.; (d) pure forests of pine, balsam, fir, cypress, and the like; and finally (e), the perennial splendors of the tropical forest, where the vegetation of the globe reaches its climax in luxuriance and variety of growth.

Practical Questions

1. Why do florists cultivate cactus plants in poor soil? (320.)
2. What would be the effect on such a plant of copious watering and fertilizing?
3. Why must an asparagus bed be sprinkled occasionally with salt? (323.)
4. If a gardener wished to develop or increase a fleshy habit in a plant, to what conditions of soil and moisture would he subject it? (320, 323.)
5. What difference do you notice between blackberries and dewberries grown by the water and on a dry hillside?
6. Are there corresponding differences in the root, stem, and leaves of plants growing in the two situations, and if so account for them?
7. When a tract of dry land is permanently overflowed by the building of a dam or levee, why does all the original vegetation die, or take on a sickly appearance? (319.)
8. Should plants with densely hairy leaves be given much water, as a general thing? (202, 320.)
9. A farmer planted a grove of pecan trees on a high, dry hilltop; had he paid much attention to ecology? Give a reason for your answer.
10. Why do the branches of trees often die, or fail to develop, on the windward side? (314.)
11. Why do trees grown in dry soil have harder wood than the same kind grown in wet soil? (123, 318.)

III. ZONES OF VEGETATION

325. The origin of vegetable zones. — The terms “zone” and “zonation” are used to express a general tendency of plant societies and formations to distribute themselves in more or less regular belts or strata, relatively to the varying intensity of the prevalent ecological factor of their habitat. In almost every locality there exists some special feature — a pond, a brook, a small ravine, an isolated hilltop, a deserted quarry, a gravel pit, or a railroad cut, — sufficiently distinct from the general surroundings to exercise a perceptible



(FIG. 422. — A pioneer colony of sumac growing on a railroad cutting. (From a photograph by J. M. Coulter.)

control over the vegetation in its immediate vicinity, and thus to become the starting point of a series of plant zones that mark the decreasing influence of the factor concerned, by their change of character as they recede from its point of greatest intensity. Starting

from a barren, exposed hilltop, for example, with a covering of dry broom sedge (*Andropogon*) and fleabane, we encounter next an almost desert zone of washed and gullied slopes in whose hard, sun-baked soil nothing but a few scrub pines and brambles can gain a foothold. This will, perhaps, be succeeded, by a straggling belt of sassafras, sumac, and buckthorn, mixed with cat brier and blackberry canes, beyond which, at the foot of the hill, begins a stretch of meadow, or a bit of woodland crossed by a brook, or hollowed into a boggy depression. From this new factor originates a second series of zonations, passing through all the stages of bog, swamp, shade, and sun

plants, back to the prevailing type of the region. Moisture is really the controlling factor in both cases, its influence in the first being negative, — that is, inversely, — and in the other, positive, or directly proportioned to the quantity present.

326. Direction of zonation. — When the direction in which the controlling factor changes is horizontal, as with soil and water, the zonation will be *horizontal*; when, as in the case of light, it is vertical, the zonation or stratification will be *vertical*. Examples of this can be observed in the growth of almost any forest area, the natural order of succession being: (1) a ground layer of mosses and fungi; (2) low, creeping vines, — partridge berry, trailing arbutus, twinflower (*Linnæa*); (3) small ferns and low flowering herbs — pyrola, clintonia, trillium; (4) a zone of tall herbs and low bushes — royal fern, cohosh (*Actæa*), blueberries; (5) tall herbs and shrubs, small trees, and climbing vines — kalmia, dogwood, farkleberry, smilax, Virginia creeper; (6) tall treetops towering up into full sunlight.

When the physical cause of intensity is a central area, such as a pond or a hilltop, the zonation will be *concentric*; that is, the different belts will succeed each other in widening circles more or less complete. Where the controlling cause extends in a line, as a river, or a chain of mountains, the zones run in parallel belts on each side of it, and the zonation is *bilateral*. In any case, however, it is seldom regular, being frequently broken and interrupted through the intervention of other factors. Nor must precisely the same kind of plants be always looked for in similar situations, though their place is usually occupied by kindred species and genera. The common pitch pine, for instance, of the Northern sand barrens is represented in sandy districts farther south by the tall, long-leaved pine, a kindred species.

327. Succession. — Zonation is a regular succession of different kinds of plants in space; there is also an analogous succession in time, as, when the vegetation of a locality is

killed off by fire or other cause, plants of an entirely different character will nearly always spring up to occupy its place. A



FIG. 423. — A thicket of pines that has succeeded a mixed growth of hard wood trees.

forest of pine, for instance, is rarely followed by conifers, but by a growth of hardwood trees, and *vice versa* — nature thus giving an impressive example as to the effectiveness of a rotation of crops.

Succession may be influenced by a variety of causes. Two

of the most efficient are: (1) the exhaustion of the soil by the long-continued growth of one formation (60), thus causing a deficiency of mineral material suited for the support of plants of that kind; (2) the migration of new species into the denuded territory where those which have different requirements as to mineral nutrients from the former inhabitants will, other things being equal, have the best chance to succeed.

328. Invasion. — A rapid and widespread occupation of any territory by a new species is called an *invasion*. Notable examples of invaders are those of the Russian thistle in the northwestern states of the Union, and the “bitterweed” (*Helenium tenuifolium*) that has almost driven out the hardy



FIG. 424. — A successful invasion — Japanese honeysuckle covering the banks of a ravine and climbing over shrubs and tree tops.

dog fennel (*Anthemis cotula*) which formerly held undisputed possession of arid places throughout the South Atlantic states. A still more remarkable instance is the invasion of the Japanese honeysuckle (*Lonicera Japonica*), originally introduced for ornament, but which has naturalized itself within the last thirty years and overrun waste places everywhere, from the Gulf to the Potomac, with a vigor and luxuriance equaled by few of our native species. As its beauty and fragrance are even more conspicuous in a state of nature than under cultivation, and as it can, moreover, be made very useful in stopping gullies and washes, its phenomenally rapid occupation of so large a territory has caused no alarm and consequently attracted little attention.

329. Climatic zones. — These are more general groupings than those we have been considering. They follow in a rough way the parallels of latitude, and are classed accordingly as: (1) tropical; (2) subtropical; (3) temperate; (4) boreal or (on mountains) subalpine; (5) arctic or (on high mountains) alpine. Taking the cultivated plants of our own country by way of illustration, we have the subtropical zone, embracing Florida and the southern portion of the Gulf states, where sugar cane, rice, and tropical fruits are the staple crops. Then comes the temperate zone, with three agricultural subdivisions: (a) the great cotton belt, with Indian corn, sweet potatoes, and the peach, melon, and fig as secondary products. Farther north, in the Central and Middle Atlantic states, we find (b) the region of maize, hemp, and tobacco, with grapes, apples, pears, cherries, and a great variety of garden vegetables as side crops. Finally comes (c) the great wheat-growing region of the North, with buckwheat, hay, and Irish potatoes as subsidiary crops.

Technically, the distribution of the natural zones of vegetation from south to north is classed under the three general heads of Forest, Grass Land, and Arctic Desert, with numerous subdivisions in each.

330. Boundaries of the zones. — While the broad continental zones of vegetation follow, in a general way, the climatic zones outlined above, they are not sharply defined, but run into each other and overlap in various degrees, so that a map depicting the range of vegetation in any wide area would show a marked deviation from those of latitude. Various other geographical factors, such as mountain ranges and bodies of water, influence the direction and character of the prevailing winds and rains, and through them the moisture and temperature, to so great an extent that they become the controlling factors over wide areas. In countries bordering on the sea, the coast line always marks a belt of its own, and on the sides of a mountain range, all the climatic zones from the equator to the pole may be repeated during an ascent of a few miles.

In our own country, where the mountain chains and coast lines run approximately north and south, the great continental zones have been superseded, for all practical purposes, by four regional divisions running almost at right angles to them. These are, disregarding minor subdivisions: —

(1) The Forest region, occupying the eastern and south central portion of the Union. In classifying this territory as forest, it is not meant to imply that it is now, or ever was, one unbroken jungle, like parts of central Africa, but that it combines the conditions most favorable to a vigorous and varied forest growth.

(2) The Plains region, extending from the very irregular western boundary of the forest region to the Rocky Mountains.

(3) The Rocky Mountain region, including the Rockies and the Sierra Nevadas with the desert area between them.

(4) The Pacific Slope, a narrow strip between the Sierras and the Pacific Ocean.

The boundaries of these regions, like those of the great continental zones, overlap in various ways, the plants of one region often appearing in another, like an arm of the sea



PLATE 15.— This giant tulip tree is a relic of the primitive forest. It is twenty-seven feet in circumference, at a distance of four feet from the ground. Notice the sharp elbows of the large boughs, a mode of branching characteristic of this kind of tree.

projecting into the land. But the district where any class of plants reaches its highest development is its proper habitat, and as a general thing the one where its cultivation pays best. It would be a waste of time and money to try to raise cotton in Maine, or cranberries in Georgia.

Practical Questions

1. Does the native wild growth of a region furnish any indication of the kind of crops which could be successfully grown there? (325, 326.)
2. Can you give a reason why the zones of cultivation may, in some cases, be more extensive than the natural range of wild plants in the same region? (262, 265.)
3. Can you give reasons why the reverse may sometimes be true? (261, 284.)
4. What crops are raised in different parts of your own state?
5. Name some of the native plants characteristic of different parts of your state. What are its principal plant formations?

Field Work

1. Ecology offers the most attractive subject for field work of all the departments of botany. It can be studied anywhere that a blade of vegetation is to be found. In riding along the railroad, there is an endless fascination in watching the different plant societies succeed one another and noting the variations they undergo with every change of soil or climate.

2. Students in cities can find interesting subjects for study in the vegetation that springs up on vacant lots, around doorsteps and area railings, and even between the paving stones of the more retired streets. On a vacant lot near the public library in Boston, over thirty different kinds of weeds and herbs were found, and in the heart of Washington, D.C., on a vacant space of about twelve by twenty feet, nineteen different species were counted. Just where such things come from, how they get into such positions, and why they stay there, will be interesting questions for city students to solve.

3. But the country always has been and always will be the happy hunting ground of the botanist. All the factors considered in the two preceding sections can hardly be found in any one locality, but by selecting areas traversed by brooks, or by gullies and ravines, very marked changes in the character of vegetation may often be observed. Barren, sandy, or rocky soils, the sun-baked clay of naked hillsides, and the borders of treeless, dusty roads will offer close approximations to xerophyte conditions.

4. If there are any bodies of water in your neighborhood, examine their vegetation and see of what it consists. Notice the difference in the shape and size of floating and immersed leaves and account for it. Note the general absence of free-swimming plants in running water, and account for it. Note the difference between the swamp and border plants and those growing in the water, and what trees or shrubs grow in or near it. Compare the vegetation of different bogs and pools in your neighborhood, and account for any differences you may observe. Compare the water plants with those growing in the driest and barrenest places in your vicinity, note their differences of structure, and try to find out what special adaptations have taken place in each case. Make a list of those in each location examined that you would class as pioneers.

5. Draw a map of the vegetation of some locality in your neighborhood that presents a variety of conditions, such as a steep hillside, a field or meadow traversed by a brook, the slopes and borders of a ravine, or the change from cultivated ground to uncultivated moor or woodland. Represent the different zones and formations by different colored inks or crayons, or by different degrees of shading with the pencil.

6. Draw a map of your state showing the different ecological regions, as indicated by the character of the native plants inhabiting them; use different colors, or light and dark shading, to define the boundaries. Notice any irregularities of outline and account for them — whether due to soil, moisture, geological formation, winds, or temperature. What is the controlling factor of each region?

Make a similar map of the cultivated plants of the different sections of your state. How do the boundaries of these formations compare with those of the native ones? If there is any difference, how do you account for it?

CHAPTER X. CRYPTOGRAMS

I. THEIR PLACE IN NATURE

331. Order of development. — All the forms that have hitherto claimed our attention belong to the great division of Spermatophytes, or seed-bearing plants, designated also as *Phanerogams*, or flowering plants. They comprise the higher forms of vegetable life, and because they are more conspicuous and better known than the other groups, they have been taken up first, since it is more convenient, for ordinary purposes, to work our way backward from the familiar to the less known, rather than in the reverse order.

But it must be understood that this is not the order of nature. The geological record shows that the simplest forms of life were the first to appear, and from these all the higher forms were gradually evolved. There is no sharp line of division between any of the orders and groups of plants, but the line of development can be traced through a succession of almost imperceptible changes from the lowest forms to the highest, and it is only by a study of the former that botanists have come to understand the true nature and structure of the latter.

332. Basis of distinction. — *Cryptogams*, or seedless plants as a whole, are distinguished from the phanerogams by their simpler structure and by their mode of propagation, which in the former is by means of spores, while in the phanerogams it is by seeds. A spore is a simple organic body, consisting usually of a single cell which separates from the parent plant at maturity and gives rise to a new individual. A seed is a complicated, many-celled structure, containing within itself the rudimentary structure of a new plant already organized.

Beginning with the simplest forms, cryptogams are grouped in three great orders : —

333. I. Thallophytes, or thallus plants. — This group takes its name from the *thallus* structure that characterizes its vegetation. In its typical form, a thallus is a more or less flat, expanded body, of which the lichens and liverworts offer familiar examples among land plants, and the kelps and laminarias among seaweeds. It may be of any size and shape, however, and sometimes consists of a mere filament, as in the common brook silk, or even of a single cell (Fig. 429). The term is applied in general to the simplest kinds of vegetable structure, in which there is no differentiation of tissues, and no true distinction of root, stem, and leaves. While it is not peculiar to the thallophytes, it has attained its most typical development among them, and the name is therefore retained as distinctive of

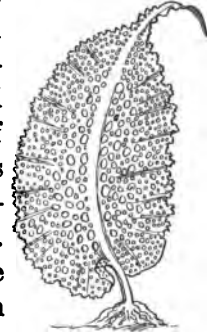


FIG. 425. — A seaweed with broad, expanded thallus.



FIG. 426. — Anthoceros, a liverwort with flat, spreading thallus.

that group. It embraces two great divisions, the Algæ and Fungi. The first includes seaweeds and the common freshwater brook silks and pond scums, besides numerous microscopic forms whose presence escapes the eye altogether, or is made known only by the discolorations and other changes caused by them in the water. To the fungi belong the mushrooms and puffballs, the molds, rusts, mildews, and the vast tribe of microscopic organisms called *bacteria*, which are so active in the production of fermentation, putrefaction, and disease.

334. II. Bryophytes, or moss plants. — This group likewise contains two main divisions, Mosses and Liverworts. Familiar examples of the latter are the flat, spreading green plants,

bearing somewhat the aspect of lichens, met with everywhere on wet rocks and banks around shady watercourses. The

name is a reminiscence of their former use in medicine as a specific for diseases of the liver, and not, as in the case of the liver leaf, of a fancied resemblance to that organ.

Mosses are one of the best defined of botanical orders, and are easily recognized by their slender, leafy fruiting stalks, growing usually in dense, spreading mats, and presenting every appearance of a highly organized structure, well differentiated into root, stem, and leaves.



FIG. 427.—A shoot of peat moss with ripe spore fruits, *f, f*.

The liverworts represent the more primitive division of the group, and in some of their forms approach so near the thallophytes that it is not difficult to recognize them as connecting links in the same chain of life. Their relationship to the next higher group is not clear, but while they represent a more primitive stage of evolution than the mosses, the development of the latter has followed a course divergent from the main line of evolutionary progress.

335. III. Pteridophytes, or fern plants, are classed roughly in the three divisions of ferns, horsetails, and club mosses. They differ greatly in structure, but all possess a vascular system, and a well-organized structure of root, stem, and leaves. They rank next to the spermatophytes in the order of development, and the group is of especial interest on account of its relationship to the higher plants. One of its divisions,



FIG. 428.—A common fern (*Polypodium vulgare*).

the club mosses, has probably given rise to at least one section of the gymnosperms, while the ferns are regarded as the ancestors of the true flowering plants, which make up the great class of angiosperms, and represent the highest type of evolution yet attained in the vegetable kingdom.

II. THE ALGÆ

MATERIAL. — Simple forms of green algæ can be found on the shady side of tree trunks, damp walls, old fence palings, and the outside of flower-pots. *Pleurococcus*, one of the commonest kinds, occurs as a green, powdery mat or felt in damp places, and is often accompanied by *protococcus*, another good specimen for study. *Spirogyra* and other filamentous algæ can be found in stagnant pools and ditches and in old rain barrels.

APPLIANCES. — Eosin solution, nitric acid, alcohol, iodine solution; a white china plate; a hand lens; a compound microscope, and slides.

336. Variety of forms. — This group embraces plants of the greatest diversity of form and structure, from the minute volvox and desmids that hover near the uncertain boundaries dividing the vegetable from the animal world, to the giant kelps of the ocean, which sometimes attain a length of from six hundred to one thousand feet. They are usually classed according to their color, as green, brown, and red algæ, including various subdivisions of each group. They all contain chlorophyll, by means of which they manufacture their own food, though in the red and brown divisions it is masked by the presence of other pigments — an adaptation to the modified light that reaches them at various depths under water. With few exceptions they can live only in the water, and unlike any other form of plant life, attain their highest development in the salty depths of the ocean. The freshwater forms are small and inconspicuous, and generally of a more simple type than the seaweeds. The great majority of them belong to the two classes of green and blue-green algæ. The former is believed to have furnished the type from which the higher plants have been evolved.

337. Study of a one-celled alga. — Put a little of the green algæ in water on a glass slide. Hold up to the light, or

over a sheet of white paper, and examine with a hand lens; then place under the microscope. It will probably be found to contain a number of minute organisms, but the pleurococci can be recognized as small round bodies of a bright green color, some of them separate, others adhering together in groups of two, four, or more, with the sides that are in contact slightly flattened. Each of these bodies is an individual plant consisting of a single cell, whence they are said to be *unicellular*. Draw one of the single cells and one of the

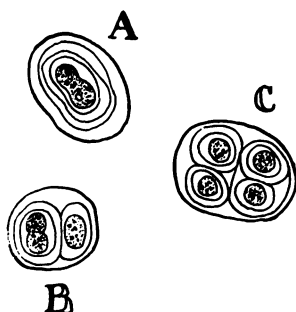


FIG. 429. — Three stages in the division of a one-celled alga (*Glæocapsa polydermatica*): A, division of a cell just beginning; B, division further advanced; C, four cells after division, remaining in contact.

groups, or colonies, as they appear under the microscope. Try to make out the cell wall and the nucleus, and label all the parts (see 7). If you have any difficulty in distinguishing the cell wall, drop a little glycerine or salt water on the slide. This will cause the cell contents to shrink by osmosis (56, 59). Can you make out the structure of the cell colonies?

They have resulted from the peculiar mode of multiplication that prevails among this class of plants. A cell elongates, contracts in the middle, and divides into two parts, each of which becomes an independent plant like the mother cell. See if you can find one in the process of division. The daughter cells repeat the process, each one giving rise to two new individuals, and so on indefinitely. The new cells do not always separate immediately on their formation, but frequently adhere together for a time, in colonies, before falling away and beginning an independent existence.

338. Reproduction by fission. — This kind of reproduction is called *fission*, or cell division, and marks a very primitive stage of development. Under stress of adverse conditions the cells formed by division may remain inactive for a time. They are then called *resting spores*, and when more favorable

circumstances arise, they begin again their work of reproduction and growth as actively as ever.

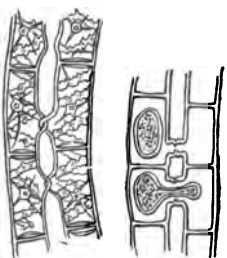
339. Meaning of the name. — The suffix *coccus* is a Latin noun (plural *cocci*) meaning a grain or berry, and is a general term applied to any small, round organism consisting of a single cell; hence, *micrococcus*, a minute round body; *protococcus*, a primitive form, or prototype of one-celled bodies; and *pleurococcus*, which may be freely translated “a one-sided little round body,” from the flattening of the adjacent sides during fission — *pleuro* meaning lateral, or pertaining to the side.

It is important to remember this definition, as the term *coccus* is of very frequent occurrence in works of biology, as a suffix for designating small round bodies of various kinds.

340. Examination of a filamentous alga. — Place on a white dish a few drops of water containing some of the green pond scum common in stagnant pools and ditches. Examine with a hand lens; of what does it appear to consist? Are the filaments all alike, or are they of different lengths and thickness? Soak a number of them in alcohol for half an hour and examine again; where has the green matter gone? Do these algæ contain chlorophyll? (336; Exp. 65.) This class are called filamentous algæ on account of their slender, threadlike thalli, which look like bits of fine floss floating about in the water. The bubbles of oxygen which they sometimes give off in great abundance cause the frothy appearance that has given rise to their popular name, “frog spit.”

341. Spirogyra. — The filamentous algæ are very numerous, and a drop of pond scum will probably contain several kinds. At least one of these, it is likely, will be a *Spirogyra*, as this is one of the commonest and most widely distributed of them all. Place a filament under the microscope and notice the spiral bands in which the chlorophyll is disposed within the cells. It is from this spiral arrangement that the species takes its name. Do you notice any

roundish particles inclosed in the chlorophyll bands? Test with a little iodine solution and see what they contain. Each filament will be seen, when sufficiently magnified, to consist of a number of more or less cylindrical cells joined together in a vertical row, and thus forming the simple



FIGS. 430, 431. — *Spirogyra* (magnified): 430, two filaments beginning to conjugate; 431, formation of spores.

threadlike thallus which characterizes this class of algæ. Physiologically, each cell is an independent individual, and often exists as such. Can you see the cell nucleus? If not, place a few filaments in a solution of eosin and add a drop of acetic acid to give the solution a pale rose color. After twenty to thirty minutes, examine again; the nucleus will be stained a deep red. If you can find an unbroken filament, examine both ends to see whether there is any differentiation of base and apex.

342. Conjugation. — See if you can find two filaments sending out lateral protuberances toward each other. Watch and notice that after a time these projections come together and unite by breaking down the cell walls dividing them, the protoplasm in each contracts, the contents of one pass over into the other, and the two coalesce, forming a new cell but little, if any, larger than the original conjugating bodies. This cell germinates under favorable conditions and produces a new individual. This method of reproduction is known as *conjugation*. The cells thus produced by the union of the contents of two separate cells may either germinate at once, and give rise to new individuals, or remain quiescent for a time, as resting spores.

Practical Questions

1. Are any of the green algæ parasitic? How do you know? (186, 336.)
2. Why is their presence in water regarded as denoting unhygienic conditions?

3. Mention some of the ways in which their presence may contribute to the contamination of drinking water.
4. Refer to Exp. 66, and account for the bubbles and froth that usually accompany these plants in the water.
5. Can you suggest any other causes than the evolution of oxygen that might produce the same effect?
6. Is the presence of these gas bubbles of any use to floating plants?

III. FUNGI

343. Classification.—In the fungi the thallus structure is greatly modified, appearing usually as a network of fine threads called the *mycelium* (pl., *mycelia*), from a Greek word meaning “fungus” (369). These plants are all, with a few doubtful exceptions, parasites or saprophytes which contain no chlorophyll and are incapable of supporting an independent existence. Biologists are divided as to their position in the genealogical tree of life. The weight of authority at present inclines to the view that they are degenerate forms derived from the algæ, but they have been so modified by their parasitic habits as to render their position

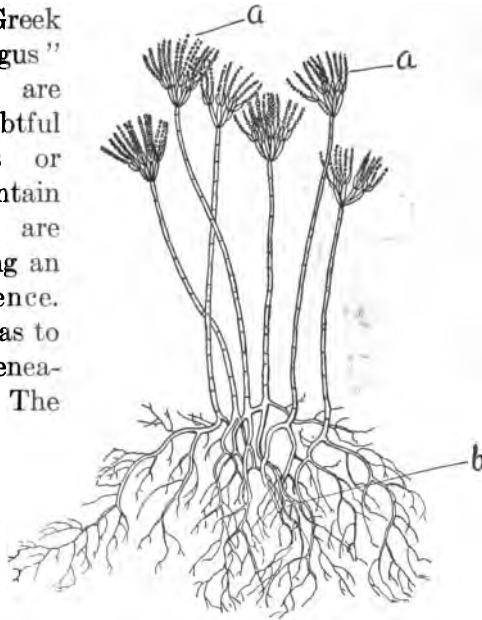


FIG. 432. — A common form of mold, magnified, showing thallus modified into a fibrous mycelium: a, a, spore cases; b, mycelium.

in the general scheme of life a doubtful one. They represent an offshoot, or side branch, as it were, of the great evolutionary line, and so may be considered for the present as standing apart in a class by themselves.

344. Numbers and variety. — Fungi exceed every other class of living organisms both in the number of species and of individuals composing them. They include such diverse forms as bacteria, molds, rusts, mildews, mushrooms, and the like, ranging in size all the way from the giant puffball, a foot or more in diameter, to the almost inconceivably minute influenza bacillus, of which nearly two thousand

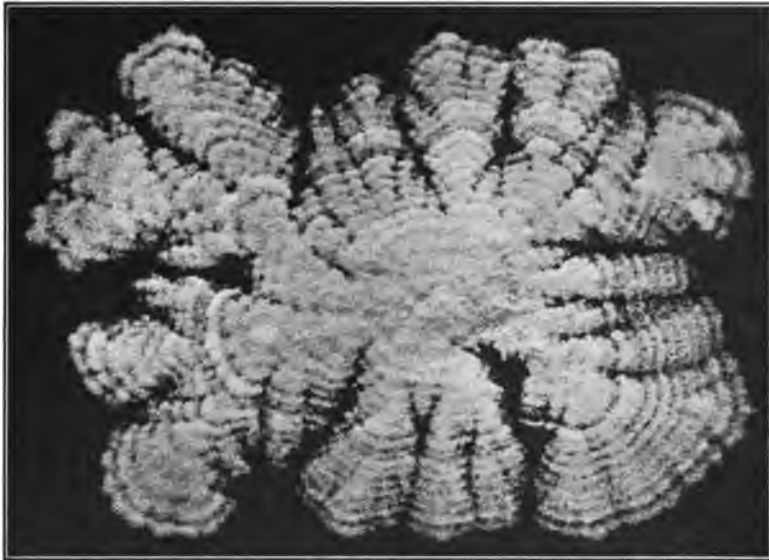
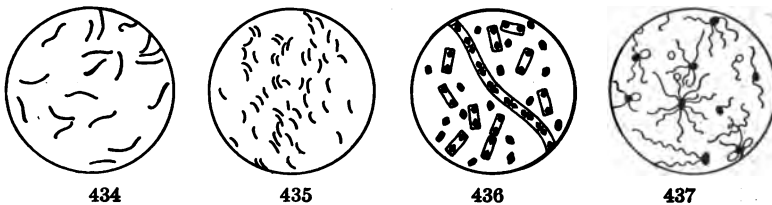


FIG. 433. — *Cephalothecium*, a fungus parasitic on rosehips — greatly magnified.
(From Mo. Botanical Garden Rep't. Photographed by Hedgcock.)

million can inhabit a single drop of water without inconvenient crowding!

345. The parasitic habit. — But while their life history is obscure and hard to trace, the fungi are, as a class, well differentiated by their parasitic habit. They contain no chlorophyll, can manufacture no food, and consequently have to obtain it ready-made from the tissues of living or dead animals and plants. On this account they are active agents in the production of disease and decay, especially certain of those manifold forms that have been grouped

together under the general head of bacteria. While not responsible for all the disease known to be caused by living organisms, — some very serious ones, such as malaria and cattle fever, being due to animal parasites, — the majority of those that have been most carefully investigated are traced to the bacteria, or other fungi. After any of these parasites have found a lodgment in the body of an organism whose tissues furnish them a congenial habitat, they multiply with enormous rapidity, and through the action of certain poisons called *toxins*, which they excrete, give rise to the most destructive diseases in both animals and plants; and no rational



FIGS. 434-437. — Disease-producing bacteria: 434, bacteria of consumption (*Bacillus tuberculosis*); 435, cholera bacillus; 436, bacilli of anthrax, showing spores; 437, typhoid bacillus.

sanitary science is possible without a knowledge of their habits and life history. Add to the vast amount of human suffering that is to be laid at their door the economic damage done by rust and smut fungi, by molds and blights and mildews, and we shall be tempted to conclude that the "battle of life" is largely a struggle against these invisible foes.

346. Useful fungi. — Not all fungi, however, are injurious. On the contrary, the great majority of them are harmless, and very many kinds are positively beneficial to man. Without the yeasts and bacteria of fermentation we could not have our bread and cheese. Other forms are active agents in the fertilization of soils, it having been estimated that there are 100,000 or more of these infinitesimal laborers at work in every cubic centimeter (about $\frac{1}{16}$ of a cubic inch) of virgin soil! Even the bacteria of putrefaction, which we are accustomed to regard as the embodiment

of all that is foul and loathesome, are engaged in an unceasing work as scavengers, without which life would no longer be possible on our globe, as will be shown in the following section.

A. BACTERIA

MATERIAL. — A vessel of water in which hay has been left to soak for several hours; a freshly boiled potato.

APPLIANCES. — A double boiler for sterilizing; a number of clean glass jars and bottles; cotton wool for stoppers; a compound microscope.

CULTURE MEDIUMS. — A freshly boiled potato answers very well for ordinary purposes. "Bread mash" can be made by drying some bread crumbs in an oven, then mashing and mixing them to a paste with boiling water; sterilize by three successive heatings in a double boiler. A sterilized preparation of gelatine solution is the medium most commonly used.

347. How to obtain specimens for observation. — While bacteria are plentiful almost everywhere, it is not always easy to capture them just when and where you want them. For this purpose, put some hay in water and leave in a warm place away from the light until the liquid becomes cloudy or a film forms on the surface. This will show that bacteria are present. If it is desired to study any particular kind of bacterium, inoculate one of the culture mediums described under "material," or a few drops of sterilized extract of beef, with a small quantity of the substance to be examined, or with dust or scrapings from the locality under consideration.

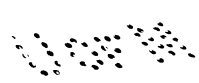
EXPERIMENT 93. BY WHAT MEANS ARE BACTERIA COMMONLY DISTRIBUTED? — Put a slice of freshly boiled potato into each of three glass tumblers and cover with a filter of cotton wool held in place by tying tightly with a cord, or by an elastic band. Set them all in a vessel of water, bring it to a boil, and keep at that temperature for half an hour, to sterilize the air in the tumblers. When they have cooled, lift the cotton from (1) for a minute or two and then replace. Carefully pass the tip of a medicine dropper through the filter of (2) so as to prevent the entrance of unsterilized air, and put on the slice of potato a small quantity of the bacterial liquid prepared as directed in the last paragraph. Leave (3) unopened. Keep all together in a warm, dark place and observe at intervals of from 12 to 24 hours. Do any bacteria appear in (3)? Do any appear on the

potato in (2), where the liquid was dropped? Are they more, or less abundant than in (1)? Since cotton wool is entirely impervious to the smallest microorganisms known, would you judge from this experiment that bacteria can get into any place unless carried there by the air, or by some other means?

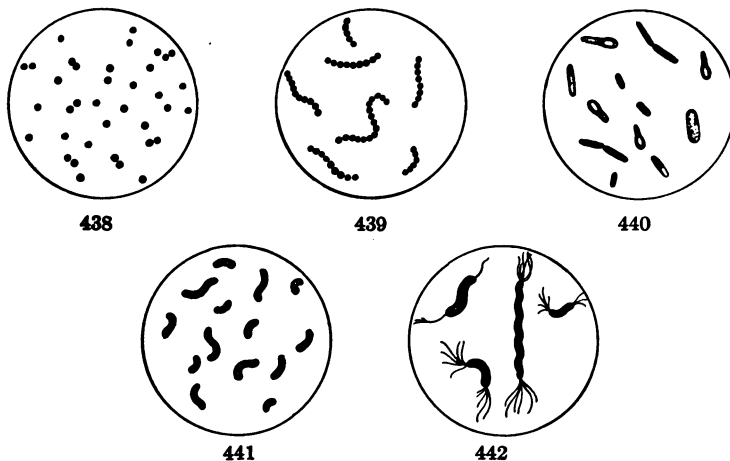
EXPERIMENT 94. CAN BACTERIA BE CARRIED BY PURE AIR? — On a warm (and preferably cloudy) day, put a slice of potato on a plate, and leave uncovered in an unused room or closet, free from dust, and kept carefully closed. Put another slice arranged in exactly the same way in an open window on a dusty street, or in a room that is used and daily swept and dusted. Do bacteria appear in the first plate? In the second? Is air free from dust a good conveyor of bacteria?

EXPERIMENT 95. WHAT CONDITIONS ARE FAVORABLE TO BACTERIAL GROWTH? — Strain some of your culture liquid into half a dozen small bottles of the same size, filling each about half full. Put (1) in a dark, cool place — on ice, if the weather is warm; (2) in a dark, warm place; (3) in a warm, well-lighted place; into (4) put a drop of carbolic acid, formalin, corrosive sublimate, or boracic acid, and keep in a dark, warm place. Keep (5) in boiling water for half an hour or more, and then place beside (2). Keep (6) in a freezing mixture of salt and ice for several hours, then place with (2) and (5). Examine all at intervals of from 12 to 24 hours. In which bottles is the presence of bacteria indicated by cloudiness of the contained liquid, or the formation of a surface film? In which do they appear first? In which most abundantly? In which last, or not at all? What is the effect of light and darkness on their growth? Of heat and cold? Of disinfectants? Name the circumstances that tend to hinder their growth, in the order of their efficacy.

348. Microscopic study of bacteria. — Put a drop of hay infusion on a slide and examine with the highest power of the microscope. You will see a multitude of very small glistening bodies including different kinds of bacteria, a majority of which are probably the hay bacillus, *B. subtilis*, shown in Figs. 443, 444. Notice that some forms move about freely, while others are non-motile. Which kind are the more numerous? The motion may be either mechanical, resembling that of the small dust particles we see dancing about in the sunshine, or apparently voluntary, and caused by the vibration of little whiplike cilia. Can you distinguish the two kinds? Try to make out clearly



the different shapes you see. Some appear as slender chains or filaments, but this is due to the individual cells' adhering together for a time before breaking up and beginning an independent existence. The small, rounded bodies, like a period (Fig. 438), are *cocci*; the slender, rod-shaped ones — sometimes slightly curved (Fig. 440) — are *bacilli* (sing., *bacillus*); the comma-shaped ones, and those generally showing a slight spiral curvature, are *vibrios* (Fig.

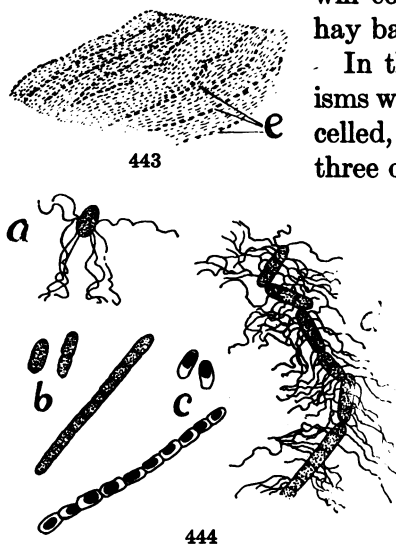


FIGS. 438-442. — Typical forms of bacteria: 438, coccus type; 439, the same, hanging together in chains; 440, rod-shaped bacteria (bacillus type), the clear areas in some of these are spores; 441, forms of vibrio; 442, forms of spirillum.

441); the spirally twisted ones, like a corkscrew (Fig. 442), are *spirilli* (sing., *spirillum*). These are the principal forms which it is important to distinguish and remember. The names are applied very loosely, however, in practice, bacillus being often used as a general term applicable to almost any kind, — the spirillum of cholera, for instance, being commonly known as the cholera bacillus, while by some authors vibrios are ranked as a variety of spirillum.

349. Life history of a typical bacterium. — A pure culture of the *Bacillus subtilis* can easily be obtained by boiling some of the hay infusion for half an hour and then leaving

in a warm place till the usual indications of the presence of bacteria appear (347). The spores of this micro-organism are so resistant that they can withstand the temperature of boiling water for several hours, while those of most other forms of bacteria are killed by a few minutes' exposure to it; hence, the crop that develops after boiling will consist of a pure culture of the hay bacillus.



FIGS. 443, 444. — Hay bacillus (*B. subtilis*): 443, a portion of the film from the culture liquid, the black lines, *e*, being bacteria in the vegetative state; 444, spore formation; *a*, *d*, motile cells and chain of cells; *b*, non-motile cells; *c*, spores and chain of spores from the film *e*.

In their active state these organisms will be seen to consist of single-celled, rod-shaped bodies, about three or four times as long as broad, and generally cohering in bands or filaments, as shown in Fig. 444, *c*. The black dots within the cells are the spores. Each individual bacterium produces but a single spore, or rather becomes a spore itself, by the contraction of its contents and the formation around them of a strong inclosing membrane. On germinating, the spores give rise to little ciliated, one-celled organisms called "swarm spores," that swim about

freely in the containing medium and multiply rapidly for a time by cell division. After this they pass again into the quiescent state, ready, whenever favorable conditions arise, to begin anew the repetition of their life cycle, which is an irregular alternation of cell division and spore formation.

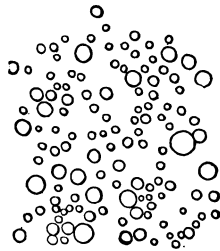
350. Resistance of spores. — Bacteriologists are not fully agreed as to the cause of spore formation, some holding that it takes place only when conditions are most favorable

for bacterial growth, others claiming the reverse. The consensus of opinion at present is toward the view that the spores are a provision for tiding over periods of stress and difficulty. They are capable of retaining their vitality for a long time, and are much harder to kill than the bacterial cells in their ordinary vegetative state, as was seen in the case of the hay bacillus. The spores of one species of potato bacillus have retained their vitality after four hours of boiling, and those of the typhoid bacillus after continuous exposure to a freezing temperature for more than three months. The majority of bacteria, in their vegetative state, are, however, either killed or rendered inert by temperatures ranging below 10° or above 50° centigrade — equivalent to about 50° and 122° Fahrenheit, respectively. It is easy to see what important bearing these facts have on the process of disinfection.

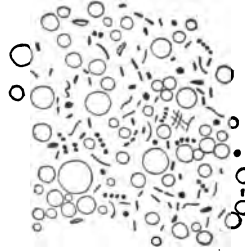
351. Reproduction and multiplication. — The ordinary mode of reproduction in bacteria, as in other unicellular organisms, is by fission (337, 338). As each individual forms but a single spore, no increase in numbers could take place by this means alone. Hence, while the spores are an important factor in the preservation of the species by continuing its existence under conditions which the active organisms could not survive, their successful propagation depends on their power of rapid multiplication by division. If this process were to go on unchecked, every hour, in an unbroken geometrical progression, the progeny of a single bacterium would, in 24 hours, number nearly 17 million; in 25 hours, 34 million; in 26 hours, 68 million, and in five days they would cover the entire surface of the globe, land and sea, to a depth of 3 feet! In ordinary standard milk sold by dairymen, and containing, when examined, less than 10,000 microbes to the cubic centimeter, — about 20 drops, — the number was found to have increased after 24 hours to 600 million. It is comforting to know, however, that the majority of these are of the harmless kinds

which are the active agents in the making of buttermilk and cheese.

The effects of their rapid multiplication will be better appreciated when we consider that bacteria are the smallest of known living creatures. If 1000 of the influenza bacilli were spread out in a single layer with their sides touching, but not overlapping, they would not take up more room than one of the periods used in punctuating this book; and a coccus concerned in a tubercular disease prevalent



445



446

FIGS. 445, 446. — Milk (highly magnified): 445, pure, fresh milk, showing fat globules; 446, milk that has stood for hours in a warm room in a dirty dish, showing fat globules and many forms of bacteria.

among cattle in South America has recently been discovered, of which double that number could be accommodated in the same space.

352. Distribution of bacteria. — Ordinary air, when free from dust, contains, on the average, not more than five germs to the liter — equal to about 1 for every 12 cubic inches. Pathogenic, or disease-producing, germs seldom occur in ordinary fresh air, and even when present are, under ordinary circumstances, harmful only to people whose bodies, by reason of physical weakness or unhygienic habits, offer a congenial soil for their multiplication. Numerous instances are known in which perfectly healthy persons have carried about infectious disease germs in their bodies and even transmitted them to others without experiencing any inconvenience, or even being aware of their presence.

Among others, the germs of pneumonia, diphtheria, and tuberculosis are often found in the mouth, nose, and sputum of perfectly healthy persons. There are also a number of bacteria that are regular inhabitants of the mouth, some of which are the cause of decayed teeth and foul breath. One form of bacterium, concerned in the production of inflammation and abscesses (*Staphylococcus*) is so constantly present on the human epidermis that one authority has declared it impossible to sterilize the skin so thoroughly as to free it entirely of this microbe. It is ordinarily not harmful unless it comes in contact with open wounds and abrasions.

353. The economic importance of bacteria. — It is hard to say whether these organisms concern us most on account of the damages attributable to them on the one hand, or the benefits we owe them on the other. If they were all as harmful as the pathogenic kinds, life would hardly be possible on the globe, while without their presence life as we know it would have ceased to be possible long ago. They are nature's great army of scavengers, the sole agents of decomposition, without which dead organic matter would be subject only to the slow changes by which the rocks and mineral matter of the earth's crust are disintegrated, and the undecomposed bodies of the vast procession of plants and animals that have existed since life first began on our globe would long ago have cumbered its surface to such an extent as to render impossible the continued development of life such as we know.

354. Sterilization is the process of ridding a substance of living microorganisms. To do this effectively, the process must be repeated several times at intervals, so as to give any spores that may have survived previous applications time to pass into the vegetative state, when their power of resistance is diminished and they are more easily destroyed. The incubation period, as the time required for the germination of the spores is called, is different for

different kinds of bacteria; hence the importance, from a sanitary point of view, of a thorough knowledge of their life history.

355. Disinfection is sterilization on a large scale, and the same principles apply to both. Heat is the safest disinfectant for objects that will bear it, if continued long enough and repeated often enough at a sufficiently high temperature. Freezing will destroy some kinds of germs and check or retard the development of nearly all, but is not to be relied on as a permanent germicide, since even among flowering plants there are many kinds, not only of seeds, but of perennial vegetative forms that are capable of enduring an arctic temperature of many degrees below freezing for long continued periods.

Chemical disinfectants act usually as microbe poisons, and are unsuitable as sterilizers for food, though valuable in the purification of houses, clothing, and utensils—especially the instruments employed in surgical operations.

The prevention of the growth of bacteria, especially in wounds and surgical incisions, whether by means of chemical or physical agencies, is known as *antisepsis*.

Practical Questions

1. Why should a person recovering from an ague continue for some time after to take quinine every third or every seventh day? (350, 354.)
2. Name some of the principal diseases produced by bacteria.
3. What is the principle to be acted on in the avoidance of such diseases? (Exps. 94, 95.)
4. Are the same means equally effective for prevention and for cure? (354, 355; Exps. 93–95.)
5. Why is “fresh air” beneficial in a sick room? (352; Exp. 94.)
6. Does it act as a disinfectant, or as a mere diluent of the infected air of the room? (352.)
7. Why ought preserved fruits and vegetables to be scalding hot when put into the can? (355.)
8. Why is it necessary to exclude the air from them? (Exps. 93, 94.)
9. Reconcile question 8 with question 5.

10. Why does the use, for drinking purposes, of water that has been boiled render a person less liable to infectious diseases? (355.)

11. Was the old-fashioned practice of handing the baby round to be promiscuously kissed by friends and neighbors a good one for the baby? (352.)

12. Why is the spitting habit to be condemned? The use of common drinking cups in schoolrooms and other public places? (352.)

13. Is it proper from a sanitary point of view that roommates at a boarding school, or even members of the same family, should use soap, towels, and other articles of the toilet in common? (352.)

B. YEASTS

MATERIAL. — A piece of fresh baker's yeast, some warm water, and a little honey or sugar solution; a pipette, or a medicine dropper; three or four clean pint bottles or preserve jars.

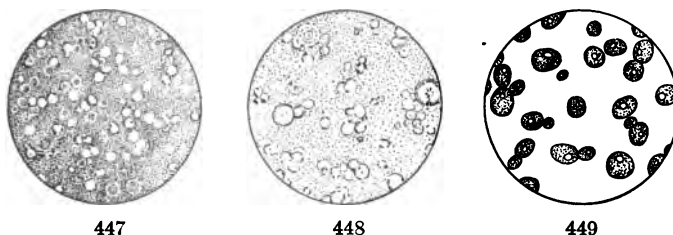
To raise a crop of yeast fungi for observation, rub one fourth of a fresh yeast cake in water enough to make a paste; add one pint of water, with a tablespoonful of honey or sugar, and stir well.

EXPERIMENT 96. WHAT CONDITIONS FAVOR THE GROWTH OF YEAST? — Pour equal parts of the liquid made as directed (see Material) into each of three pint bottles, stopper lightly, and label. Put (1) in a warm, dark place; (2) in a cool, dark place; and (3) in a bright light in a warm place. Observe at intervals of a few hours the changes that occur in each. Notice the bubbles that rise from the liquid. In which bottle do they form most rapidly? Lower a lighted match into it, or transfer some of the gas with a pipette into a vessel containing limewater, and tell what it is. Taste some of the fermenting liquid. Is it sweet? What has become of the sugar that was put into it?

356. Yeasts and ferments. — Yeasts belong to a very different order of fungi from the bacteria, but on account of their simplicity of structure and the similarity of their action to that of some of the latter, it is usual to consider them together. They are the active agents of fermentation, and include a large number of species. The kind used for household purposes is the same as that employed in making beer. Of this species there are many varieties, each one of which gives a characteristic taste to the beer made from it; and brewers, by paying attention to the cultivation of yeasts, give their product the special flavors peculiar to the different

brands. This kind of yeast is not known to exist except in a state of cultivation, and probably owes its survival and present condition of development to a symbiosis with man, on account of its usefulness in bread making, and still more, perhaps, to its part in the gratification of his bibulous propensities, for among savage tribes the manufacture of fermented liquors is practiced long before the wholesome art of bread making.

There are other yeasts existing in a state of nature, such as those on the surface of fruits, which cause the latter, under



FIGS. 447-449. — Forms of common yeast (*Saccharomyces cerevisiae*): 447, brewers' yeast; 448, household yeast (the large grains are starch); 449, yeast from beer sediment, showing budding. (Figs. 447, 448 $\times 250$; Fig. 449 $\times 1270$.)

certain circumstances, to ferment and decay. For this reason artificial ferments are not needed in making wine and other alcoholic liquors from fruits. Fermentation is also caused by certain forms of bacteria, as in the formation of vinegar and the souring of milk. Such bacteria often contaminate the yeast ferments.

357. Microscopic examination. — Place a drop of the cultural liquid on a slide and examine under the highest power of the microscope. What do you see? These egg-shaped bodies are yeast plants, unicellular organisms like the pleurococcus. Do you see any chlorophyll? Are the yeasts parasitic? How do you know? What do they live on? (Suggestion: What food substance that has disappeared was put into the culture liquid?) In getting their nourishment from the sugar, these fungi disintegrate it into alcohol and carbon dioxide, which is a process of fermentation. It

is the bubbles of gas that were seen rising in the liquid which cause beer to effervesce and bread to rise. They permeate the dough and by their expansion produce the sponginess peculiar to leavened bread. Look for a cell with a bud forming on it; from what part does it appear to grow? Where a number of buds remain for some time attached to the mother cell (Fig. 449), they form a *colony*. Make a sketch of a single cell and of a colony of two or more adherent ones, labeling all the parts. If the cell wall cannot be made out clearly, run a little glycerine, or salt water, under the cover glass with a medicine dropper. What causes the contents of the cell to contract and leave the wall? (56, 59.)

358. Reproduction. — From time to time buds break away from the mother cell and form new individuals or colonies of their own. This process is called multiplication by budding, and is only another form of cell division.

Whenever reproduction takes place by other means than seeds or spores, it is said to be *vegetative*. This sort of reproduction is not confined to unicellular plants, but exists also among the phanerogams, the propagation of species by means of buds, tubers, rootstocks, runners, grafting, and the like being variations of the same process. On the other hand, yeasts and bacteria and the unicellular algæ have the power, under extreme conditions, to form resting spores, which sometimes lie dormant for years and resume their activity when favorable conditions return.

Practical Questions

1. When is fermentation useful to man?
2. What is the effect on canned fruits and vegetables if yeast cells get into them?
3. Why does milk turn sour in warm weather? (350, 351; Exp. 96.)
4. Why do buttermilk and clabber spoil if left standing too long? (345, 356.)
5. What causes bread to be "heavy"? (356, 357.)
6. Why will dough not rise unless kept in a warm place? (Exp. 96.)
7. Why is beer kept cold during fermentation? (350, 356.)

C. RUSTS

MATERIAL. — A leaf of wheat affected with red rust; a leaf or a stalk with black rust. Some barberry leaves with yellowish pustules on the under side, which under the lens look like clusters of minute white corollas. These are popularly known as "cluster cups." As the spots on barberry occur in spring, the red rust in summer, and the black rust in autumn, gather the specimens as they can be found, and preserve for use.

The orange leaf, or brown, rust (*Puccinia rubigo-vera*) is more common in some parts of the country than the ordinary wheat rust (*Puccinia graminis*), but the two are so much alike that the directions given will do for either. If the orange leaf-rust (so named from its color, and not from any connection with orange leaves, the logical relation of the words being orange leaf-rust, and not orange-leaf rust) is used, the cups and pustules should be looked for on plants of the borage family — comfrey, hound's-tongue, etc. The orange leaf-rust of apple is caused by a fungus which will serve to illustrate the same class of parasites. The "teleuto" stage of this will be found on cedar trees, in the excrescences commonly known as "cedar apples"; the "cluster cups" on the leaves of apple and haw trees affected with the disease.

359. Red rust. — Uredo stage. Examine a leaf of "red rusted" wheat under the lens, and notice the little oblong brown dots that cover it. These are clusters of spore cases, and are the only part that appears above the surface. Viewed under the microscope, the red rust will be seen to consist of a mycelium (see Fig. 432), which ramifies through the tissues of the leaf and bears clusters of single-celled reddish spores that break through the epidermis and form the reddish brown spots and streaks from which the disease takes its name. These spores, falling upon other leaves, germinate in a few hours and form new mycelia, from which, in six to ten days, fresh spores arise. Formerly this was thought to complete the life history of the fungus, to which the name of *Uredo* was given. It is now known, however, that the red rust is merely a



FIGS. 450, 451. — Leaf of wheat affected with orange leaf-rust (*Puccinia rubigo-vera*), uredo stage: 450, upper side of leaf; 451, under side.

stage in the life cycle of the plant, and to this stage the old name uredo is applied, the spores being called *uredo-spores*.

360. Black rust. — Teleuto stage. Next examine with a lens a part of the plant attacked by black rust. Do you

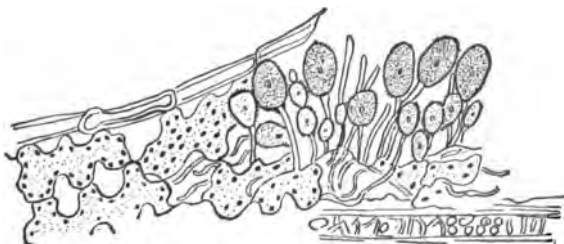


FIG. 452. — Uredo spores of wheat rust (*Puccinia graminis*), magnified. (From COULTER's "Plant Structures.")

observe any difference except in the color? Do the two kinds of rust attack all parts of the plant equally?

If not, what part does each

seem to affect more particularly? At what season does the black rust appear most abundantly? Place a section of the diseased part under the microscope and notice that the difference in color is due to a preponderance of long, two-celled bodies with very thick, black walls (Fig. 453). These

are called *teleutospores*, a word meaning "final spores," because they are formed only toward the end of the season. They are developed from the same mycelium with the uredospores, and are not a

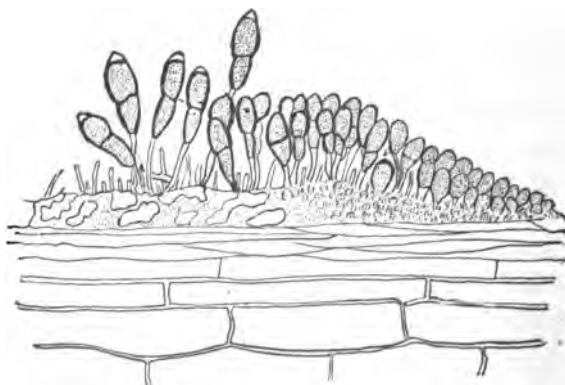


FIG. 453. — Teleutospores of wheat rust, magnified. (From COULTER's "Plant Structures.")

product of the latter, but collateral with them and belong to the same stage in the life history of the fungus. After they appear, the uredospores cease to be developed at all, and

only the dark teleutospores are produced. These remain on the culms in the stubble fields over winter, ready to begin the work of reproduction in spring. For this reason the teleutos are popularly known as "winter spores" in contradistinction to the uredos, or "summer spores," whose activity is confined to the warm months.

It was formerly supposed that black rust was caused by a different fungus from that producing red rust, and to it the name *Puccinia* was given. This has been retained as a general designation for all fungi undergoing these two phases, and the particular form of fungus that we are now considering is known in all its stages as *Puccinia graminis*.

361. The nonparasitic stage.—The formation of teleutospores completes that portion of the life history of the fungus during which it is parasitic on wheat and grasses of different kinds. In spring they begin to germinate on the ground, each cell producing a small filament, from which arise in turn several small branches. Upon the tip of each of these branches is developed a tiny sporelike body called a *sporidium* (Fig. 454), which continues the generation of the rust fungus through the next stage of its existence. The filament which bears these sporidia is not parasitic, but when the sporidia ripen and the spores contained in them are scattered by the wind, there begins a second parasitic phase, which forms the most curious part of this strange life history.

362. The æcidium.—Examine next the under side of some barberry leaves (or comfrey, etc., if orange leaf-rust is used) for clusters of small whitish bodies that appear under the lens like little white corollas with yellow anthers in the center. Examine a section of one of these under the

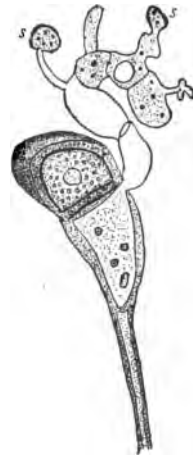


FIG. 454.—Teleutospore germinating and forming sporidia, s, s. (From COULTER'S "Plant Structures.")

microscope and notice that the yellow substance is composed of regular layers of colored spores. The corolla-like receptacles containing them, popularly known as "cluster cups," are borne on a mycelium produced from the spores described in the last paragraph. This mycelium is parasitic on barberry or other leaves, according to the kind of fungus, and was long believed to be a distinct plant, to

which the name *Æcidium* (pl., *Æcidia*) was given. This term is now applied to the cluster cups, and those fungi which at any period of their life history produce them are called æcidium fungi.

363. *Spermogonia*.

—On the upper surface of the leaves that bear the æcidia, notice some small black dots hardly larger than pin points, but which, when sufficiently magnified, appear as little

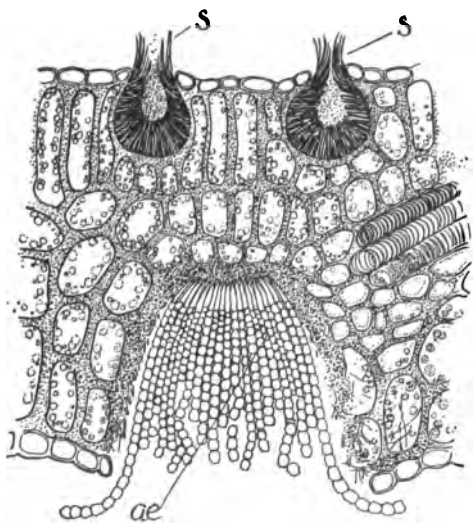


FIG. 455.—Section through a barberry leaf, showing on the upper side two spermogonia, *s,s*; and on the under side, an æcidium, *æ*.

flask-shaped bodies (Fig. 455) under the epidermis. These are known as *spermogonia*, or *pycnidia*. When mature, they break through the epidermis so that the necks protrude, and discharge a quantity of minute cells or spores, very like some that, later on, we shall find playing an important part in the reproductive processes of certain other fungi, and of mosses and liverworts. In the rust fungi, however, their function is not understood. They may possibly be survivals of organs which were once active in the life processes of the plant, but have become useless under changed conditions. Do such organs throw any light on the evolutionary history of plants?

364. Connection between barberry and wheat rust. —

With the discharge of the æcidium spores, the part of the life cycle of the fungus spent on the barberry comes to an end, and it is ready to begin the uredo-teleuto stage over again as soon as it finds a suitable host. Where there are no barberries, it is capable of propagating without them, either by adapting itself to some other host plant, or by omitting the æcidium stage altogether. The parasitic habit being an acquired one, the fungus, like some animal organisms that we know of, can often be "educated" by force of circumstances into tolerating, and even thriving upon, foods which under other circumstances it would reject. The wheat rust is known to be capable of propagating year after year in the uredo stage, the spores surviving



FIG. 456. — A species of "cedar apple" (*Gymnosporangium*), showing the uredo-teleuto stage of the apple rust fungus. (From a photograph by Prof. F. E. Lloyd.)

through the winter on volunteer grains and grasses; and in no other country in the world does rust do greater damage to the wheat crop than in Australia, where the barberry is practically unknown. This power of accommodation possessed by many parasites is one of the difficulties the agriculturist has to contend with in the development of rust-proof varieties.

365. Polymorphism. — Plants that pass through different stages in their life history are said to be *polymorphic*, that

is, of many forms. The habit is very common among the lower forms of vegetation. The fact that one or more of the phases are sometimes omitted, as the æcidium phase of wheat rust in warm climates, suggests the idea that it may be of use in helping the plant to tide over difficult conditions. Besides giving better chances of obtaining nourishment, it probably has the same effect as cross fertilization among flowering plants, in imparting increased strength and vitality to the succeeding generation. Wheat rust produced from barberry æcidia is said to be much more vigorous — and consequently more destructive — than when derived from a uredo that has reproduced itself for several generations.

366. The damage done by rust to the host is through the destruction of its tissues by the mycelium. The chlorophyll is destroyed so that the plant can no longer manufacture food, and is too starved to produce good grain. There are many varieties of wheat rust, which have been found on twenty-seven different kinds of grain. Most of them are specialized to a particular host plant and will not, ordinarily (364), infest any other. Has this fact any bearing upon the production of rustproof varieties?

Practical Questions

1. Is a farmer wise to leave scabby and mildewed weeds and bushes in the neighborhood of his grain fields? (364, 365.)
2. Are there any objections to the presence of volunteer grain stalks along roadsides and in fence corners during winter? (364.)
3. Should cedar trees be allowed to grow near an apple orchard? Give a reason for your answer. (p. 317, Material.)
4. Should diseased plants be plowed under? (361.)
5. What disposition should be made of them?
6. Ought diseased fruits to be left hanging on the tree?
7. Why is it necessary to pick over and discard from a crate or bin all decaying fruits and vegetables?
8. Does a rotation of crops tend to prevent the spread of disease in plants? Give reasons for your answer.
9. Are rustproof varieties to be relied on indefinitely? (364.)

D. MUSHROOMS

MATERIAL. — Any kind of gilled mushroom in different stages of development, with a portion of the substratum on which it grows, containing some of the so-called spawn. The common mushroom sold in the markets (*Agaricus campestris*) can usually be obtained without difficulty. Full directions for cultivating this fungus are given in Bulletin 53 of the U. S. Department of Agriculture. From 6 to 12 hours before the lesson is to begin, cut the stem from the cap of a mature specimen, close up to the gills, lay it, gills downward, on a piece of clean paper, cover with a bowl or pan to keep the spores from being blown about by the wind, and leave until a print (Fig. 466) has been formed.

367. Mushrooms and toadstools. — The popular distinction which limits the term "mushroom" to a single species, the *Agaricus campestris*, and classes all others as toadstools, has no sanction in botany. All mushrooms are toadstools and all toadstools are mushrooms, whether poisonous or edible. The real distinction is between mushrooms and puffballs, the former term being more properly applied to fungi which have the spore-bearing surface exposed.

368. Examination of a typical specimen. — The most highly specialized of the fungi, and the easiest to observe on account of their size and abundance, are the mushrooms that are such familiar objects after every summer shower. The *gilled* kind — those with the rayed laminae under the cap — are usually the most easily obtained. Specimens should be examined as soon after gathering as possible, since they decay very quickly.

369. The mycelium. — Examine some of the white fibrous substance usually called spawn through a lens. Notice that it is made up of fine white threads interlacing with each other, and often forming webby mats that ramify to a considerable distance through the substratum of rotten wood or other material upon which the fungus grows. This webby structure, often mistaken for root fibers, is the thallus or true vegetative body of the plant, the part rising above ground, and usually regarded as the mushroom, being only the fruit, or reproductive organ. Place some of the mycelium

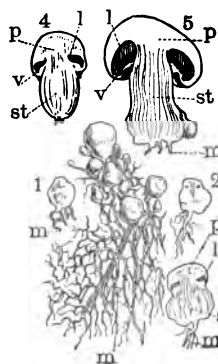


FIG. 457. — Mycelium of a mushroom (*Agaricus campestris*), with young buttons (fruiting organs) in different stages: 1, 2, 3, 4, 5, sections of fructification at successive periods of development; *m*, mycelium; *st*, stipe; *p*, pileus; *l*, gill, or lamina; *v*, veil.

under the microscope and notice that it is composed of delicate filaments made up of single cells placed end to end, as in *Spirogyra* (341). These filaments are called *hyphæ*.

370. The button. — Look on the mycelium for one of the small round bodies called buttons (Fig. 457). These are the beginning of the fruiting body popularly known as the mushroom, and are of various sizes, some of the youngest being barely visible to the naked eye. After a time they begin to elongate and make their way out of the substratum.

371. The veil and the volva. — Make a vertical section through the center of one of the larger buttons after it is well above ground, and sketch. Notice whether it is entirely enveloped from root to cap in a covering membrane — the *volva* (Fig. 458, *a*) — or whether the enveloping membrane extends only from the upper part of the stem to the margin of the cap — the *veil* (Fig. 458, *d*); whether it has both veil and volva, or finally, whether it is naked, that is, devoid of both.

372. The stipe, or stalk. — Notice this as to length, thickness, color, and position; that is, whether it is inserted in the center of the cap or to one side (excentric), or on one edge (lateral). Observe the base, whether bulbous, tapering, or straight, and whether surrounded by a

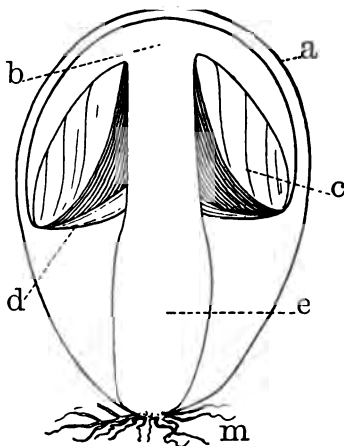


FIG. 458. — Diagram of unexpanded *Amanita*, showing parts: *a*, volva; *b*, pileus; *c*, gills; *d*, veil; *e*, stipe; *m*, mycelium.

cup, or merely by concentric rings or ragged bits of membrane (the remains of the volva). Look for the *annulus* or ring (remains of the veil) near the insertion of the stipe into the cap, and if there is one, notice whether it adheres to the stipe, or moves freely up and down (Fig. 459, *a*); whether it is thick and firm, or broad and membranous so that it hangs like a sort of curtain round the upper part of the stipe (Fig. 467, *a*). Break the stem and notice whether it is hollow or solid; observe also the texture, whether brittle, cartilaginous, fibrous, or fleshy.

373. The pileus, or cap. — Observe this as to color and surface, whether dry, or moist and sticky; smooth, or covered with scurf or scales left by the remains of the volva, as it was stretched and broken up by the expanding cap (Fig. 459, *p, p*). Note also the size and shape, whether conical, expanded, funnel-shaped (Fig. 460), or *umbonate* — having a protuberance at the apex (Fig. 459) — or whether the margin is turned up at the edge (revolute, Fig. 467), or under (involute, Fig. 459).

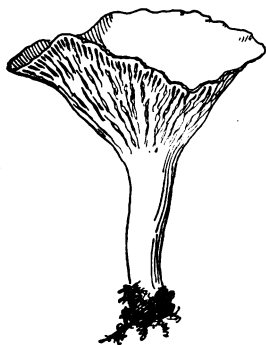


FIG. 460. — Chanterelle (*Cantharellus cibarius*), with infundibuliform pileus and decurrent gills.

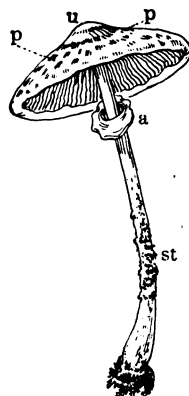
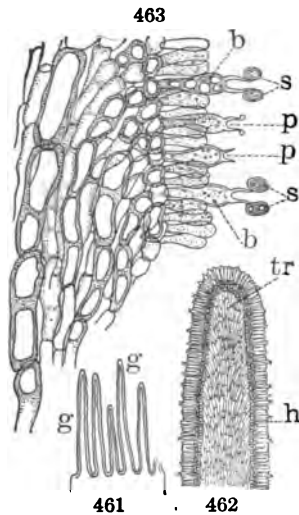


FIG. 459. — Parasol mushroom (*Lepiota procera*), showing movable annulus: *st*, stipe; *a*, annulus, or ring; *u*, umbo; *p, p*, floccose patches left by volva.

374. The gills, or laminæ. — Look at the under surface and notice whether the gills are broad or narrow, whether they extend straight from stem to margin, or are rounded at the ends, or curved, toothed, or lobed in any way. Notice their attachment to the stipe,

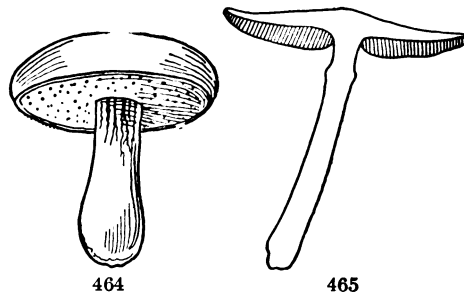
whether *free*, not touching it at all; *adnate*, attached squarely to the stem at their anterior ends; or *decurrent*, running down on the stem for a greater or less distance (Fig. 460).

375. The hymenium. — Cut a tangential section through one side of the pileus and sketch the section of the gills as they appear under a lens, or a low power of the microscope. Notice



FIGS. 461-463. — Section of a gilled mushroom: 461, through one side, showing sections of the pendent gills, *g, g* (slightly magnified); 462, one of the gills more enlarged, showing the central tissue of the trama, *tr*, and the broad border formed by the hymenium, *h*; 463, a small section of one side of a gill very much enlarged, showing the club-shaped basidia, *b, b*, standing at right angles to the surface, bearing each two small branches with a spore, *s, s*, at the end. The sterile paraphyses, *p*, are seen mixed with the basidia.

463), while others remain sterile. The spore-bearing cells are called *basidia*; the sterile ones, *paraphyses*; and the whole spore-bearing surface together, the *hymenium*, from a Greek word meaning a membrane. It is from the presence



FIGS. 464, 465. — A tube fungus (*Boletus edulis*): 464, entire; 465, section, showing position of the tubes.

of this expanded fruiting membrane that the class of mushrooms we are considering gets its botanical name, *Hymenomyces*, membrane fungi. The hymenium is not always borne on gills, but is arranged in various ways which serve as a convenient basis for distinguishing the different orders. In the tube fungi, to which the edible boletus belongs (Figs. 464, 465), the basidia are placed along the inside of little tubes that line the under side of the pileus, giving it the appearance of a honeycomb. In another order, the porcupine fungi, they are arranged on the outside of projecting spines or teeth, while in the morels they are held in little cups or basins.

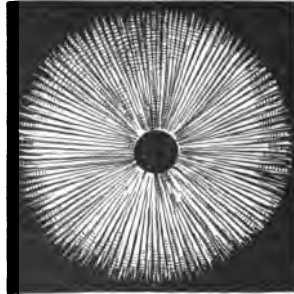


FIG. 466. — Spore print of a gilled mushroom.

376. Spore prints. — When the gills are ripe, they shed their spores in great abundance. Take up the pileus that was laid on paper, as directed under Material, on page 323, and examine the print made by the discharged spores; it will be found to give an exact representation of the under side of the pileus.

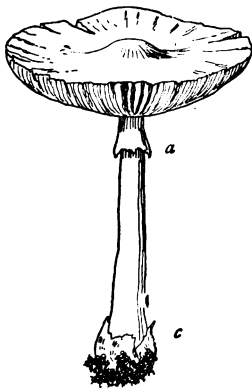


FIG. 467. — Deadly agaric (*Amanita phalloides*), showing the broad pendent annulus, *a*, formed by the ruptured veil; the cup at the base, *c*, and floccose patches on the pileus, left by the breaking up of the volva.

377. The spores. — Notice the color of the spores as shown in the print. This is a matter of importance in distinguishing gill-bearing fungi, which are divided into five sections according to the color of the spores. One source of danger, at least, to mushroom eaters would be avoided if this difference was always attended to, for the deadly amanita (*Amanita phalloides*) and the almost equally dangerous fly mushroom (*A. muscaria*) both have white spores,

while the favorite edible kind (*Agaricus campestris*), though white-gilled when young, produces dark, purple-brown spores that cannot fail to distinguish it clearly for any one who will take the trouble to make a print.

378. Economic properties. — Most of the wood-destroying fungi belong to this and allied orders. They are among the worst enemies the forester has to deal with (140), and



FIG. 468. — Portion of the root of a maple affected with rot caused by the mycelium of a fungus that has penetrated to its interior.

millions of feet of lumber are destroyed every year by them.

Over seven hundred kinds of fungi growing in the United States have been described as edible, but the evil repute into which the whole class has been brought by the poisonous qualities of a few species, and the difficulty, to any but an expert, of distinguishing be-

tween these and the harmless kinds, has caused them to be generally neglected as articles of diet. While they are pleasant relishes and furnish an agreeable variety to our daily fare, their food value has been greatly exaggerated. They contain a large proportion of water, often over 90 per cent, and the most valued of them, the *Agaricus campestris*, is about equivalent to cabbage in nutrient properties.

Practical Questions

1. Why are mushrooms generally grown in cellars? (186, 343.)
2. Name any fungi you know of that are good for food or medicine or any other purpose.
3. Name the most dangerous ones you know of.

4. Do you find fungi most abundant on young and healthy trees, or on old, decrepit ones? Account for the difference. (141, 343, 378.)
5. Do you ever find them growing on perfectly sound wood anywhere?
6. Are they ever beneficial to a tree? (86.)
7. Is it wise to leave old, unhealthy trees and decaying trunks in a timber lot?

IV. LICHENS

MATERIAL. — Specimens can be found almost everywhere, growing on rocks, walls, logs, stumps, and trees. Some of the more common kind are: *Parmelia*, recognizable by the shallow spore cups borne on the upper surface of the thallus; *Cladonia*, by the little stalked receptacles, like goblets, in which its spores are held; *Phycia*, by its bright orange color. Where practicable, it is well to have several different kinds for comparison. Iceland moss (*Cetraria islandica*) can generally be obtained from the grocers, and is a good example of an intermediate form between foliaceous and fruticose lichens.

If the specimens are very dry, they will be too brittle to handle conveniently, and should be moistened by soaking a short time in water. This will render them quite flexible and also bring out the green color more clearly.

379. Examination of a typical specimen. — The commonest kind of lichens, and generally the most easily ob-

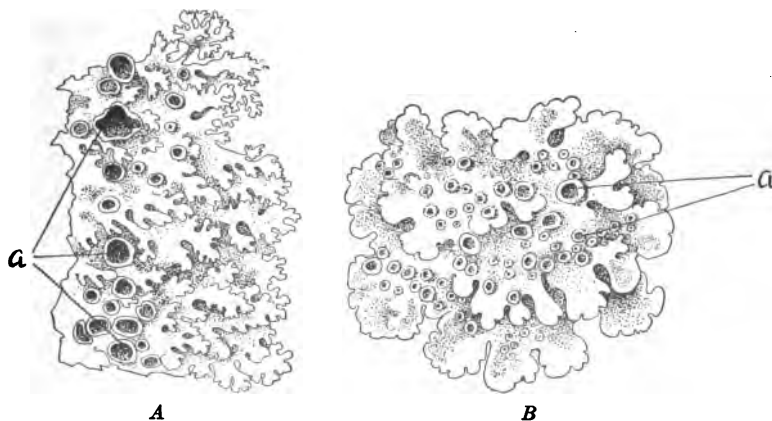


FIG. 469. — Foliaceous lichens: A, *Xanthoria* (*Phycia*) *parietina*; B, *Parmelia* *conspersa*; a, spore cups.

tained, are those that grow on rocks and tree trunks in flat, spreading patches. Their margins are much dented and

curled, giving them a somewhat leaflike appearance, whence they are called "foliaceous" lichens. This broad, expanded body is the thallus, or vegetative part, as distinguished from its reproductive part. Examine carefully the thallus of your specimen. Note the size and shape of the indentations. Is there any order or regularity about them, such as was observed in the lobing of leaves? Is there any difference in color between the upper and under sides? What other differences do you notice? Do you see anything like hairs, or rootlets, on the under side? Mount one of them in water and place under the microscope. What does it look like? Compare with one of the hairs from a leaf of mullein, gromwell, blueweed, or other hairy plant, with the hypha of a fungus mycelium, and with your study of the root hair in 67 (a). Is it a hair or a root? These rootlike hairs are called *rhizoids*, and serve to anchor the lichen to its substratum. Look on the upper side for little cup-shaped or saucer-shaped receptacles. On what part of the thallus

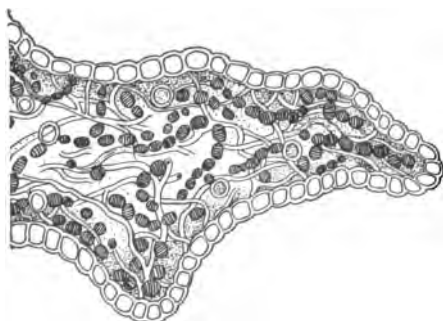


FIG. 470. — Portion of the thallus of a lichen, magnified, showing imprisoned algæ.

are they situated? Examine with a lens and see if you can make out what they contain. These cups are the spore cases. The lichen fungus belongs to the division of sac fungi which produce their spores in closed sacs, or cups.

380. Structure of the thallus. — Make a thin

section through a thallus and place under the microscope. Notice the small green bodies enveloped in the hyphæ of the fungus. Are they most abundant near the upper or the lower epidermis? Has their green color anything to do with this, and with the difference in color between the two surfaces of the thallus? (184.) Do they look like chlorophyll granules?

Can you tell what they are? Compare with your study of the unicellular algæ (337) and with Fig. 429. Does this throw any light on their real nature?

381. The lichen thallus a composite body.— You will probably have no difficulty in making out that these small round bodies are green algæ of some kind, but of what species will depend upon the kind of lichen with which it is associated. In *Cladonia* and the bearded lichen (Fig. 473), it is a proto-coccus; in other forms, a pleurococcus or a nostoc—and so on, each species of lichen fungus being specialized to a certain form of alga. The great botanist, De Bary, showed

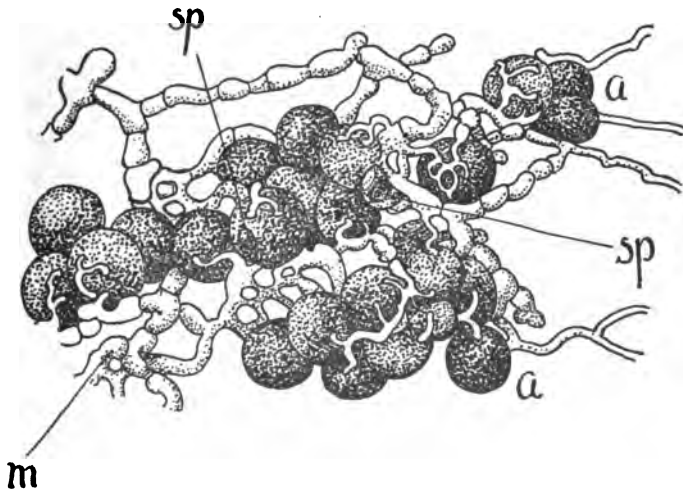


FIG. 471.— Artificial lichen mycelium, *m*, made by sowing spores of a fungus, *sp*, among alga cells, *a*.

that it is even possible to produce a lichen thallus artificially by sowing the spores of a fungus among the cells of the particular alga with which it is able to unite. The spores will germinate without the alga, but soon perish unless they come in contact with the right one. It is thus made clear that the lichen plant as a whole is a combination of elements belonging to two distinct orders, the algæ and fungi, but so closely associated as to constitute practically a single individual.

382. Slavery, or partnership? — Now, what can be the object of this peculiar association? Is it a symbiosis, or a case of enslavement? The fungi, as we know, are all parasites, unable to manufacture their own food or to exist at all except at the expense of other organisms, living or dead. But the lichens have refined upon the gross rapacity of their order, and instead of indiscriminately destroying the hosts that furnish their nourishment, have used their victims to better purpose by converting them into contented, well-fed slaves! The imprisoned algæ perform for them the same service that the chlorophyll bodies do for the higher plants, and so the lichen fungi have the advantage of other parasites in getting their food manufactured at home, so to speak. And while the algæ have to do double work in order to feed both themselves and their masters, the fungus, in return, shelters them against cold and drought, and prolongs their growing period by giving them a more continuous supply

of moisture and food materials, which it draws from the substratum by means of its rhizoids. In this way both plants are enabled to live in situations that neither could occupy without the other.

383. Reproduction. — The multiplication of the lichen algæ is exclusively vegetative. The fungus, on the other hand, reproduces normally by spores, and the fruiting bodies found on the thallus originate from the fungus mycelium.

384. Classification. — To be strictly accurate, the two kinds of vegetable bodies

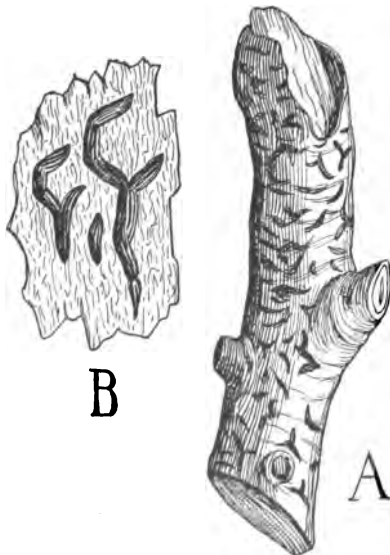
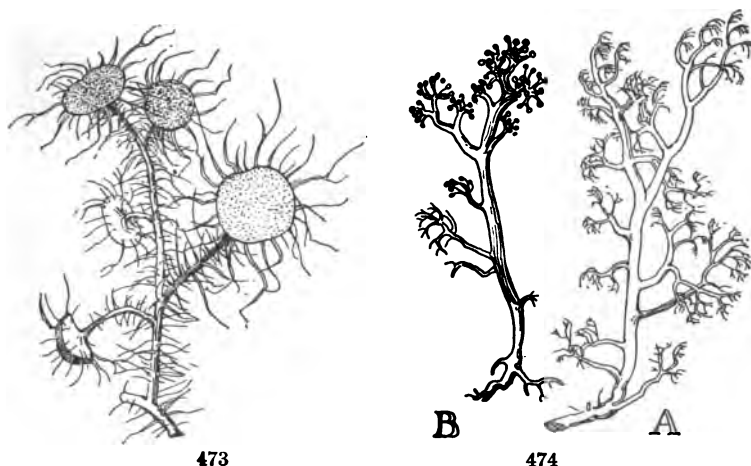


FIG. 472. — A crustaceous lichen (*Graphis elegans*) growing on holly: A, natural size; B, slightly magnified.

that make up the lichen thallus would probably have to be classified separately, as algæ or fungi, respectively, but as fructification is the generally accepted basis of classification, and the plant body is too intimately permeated with both kinds of tissue to be divided, each lichen body as a whole is classed with its particular kind of fungus. The entire group, on account of the distinctive characters that mark it, is



FIGS. 473, 474.—Fruticose lichens: 473, *Usnea barbata*, bearded lichen; 474, *Cladonia rangiferina*, reindeer moss: A, sterile; B, fruiting portion.

placed in a separate order of its own. This includes three principal divisions, distributed according to the shape of the thallus, and its habit of growth: (1) *Crustaceous*, those that adhere closely to the substratum, as if glued or inscribed on it; (2) *Foliaceous*, with a broad, more or less lobed and leaf-like thallus that adheres loosely to the substratum by means of rhizoids springing from its under surface; (3) *Fruticose*, with branching, stemlike thallus attached at the base like a regularly rooting plant (Figs. 473, 474). Among these are the Iceland moss, used as an article of food by man, and the reindeer moss (*Cladonia rangiferina*), which is the chief sustenance of the reindeer.

Practical Questions

1. Have lichens any economic value? (384.)
2. In what way are they most useful? (320.)
3. Do you find them, as a general thing, on healthy young trees and boughs, or on old ones, and those showing signs of decay?
4. Do you ever find them growing on trees or other objects in densely inhabited areas, — cities, large towns, and manufacturing centers?
5. Do they grow more thickly on the shady (northern) side of rocks, walls, and trees growing in the open, than on the sunny and (presumably) warmer sides?
6. Mention some ways in which a growth of lichens might be beneficial to a tree.
7. In what ways could it be harmful?

V. LIVERWORTS

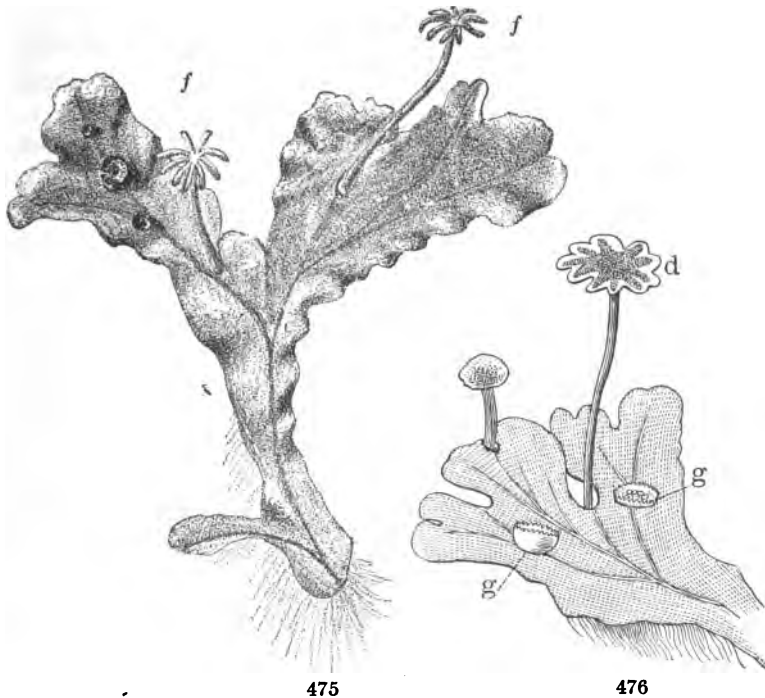
MATERIAL. — Liverworts can generally be found growing with mosses in damp, shady places, and are easily recognized by their flat, spreading habit, which gives them the appearance of green lichens. *Marchantia polymorpha* (Fig. 475), one of the largest and best specimens for study, is common in shady, damp ground throughout the states. It is dioecious, and specimens bearing both male and female organs should be provided. *Lunularia*, a smaller species that can be recognized by the little crescent-shaped receptacles on some of the divisions of the thallus, is abundant in greenhouses on the floor, or on the sides of pots and boxes kept in damp places; but the spore-bearing receptacles are seldom or never present, the species being an introduced one and possibly rendered sterile by changed conditions. *Anthoceros* (Fig. 426) and leafy liverworts, such as that shown in Fig. 484, also make good examples for study.

EXPERIMENT 97. WHY ARE THE UPPER AND UNDER SIDES OF A LIVERWORT DIFFERENT? — Plant a growing branch of *Marchantia*, or of any flat, spreading liverwort, in moist earth so that the upper side will lie next the soil, and watch for a week or two, noting the changes that take place. What would you infer from these as to the cause of any differences that may have been observed between the two surfaces?

385. Examination of a typical liverwort — The thallus. — The broad, flat, branching organ that forms the body of the plant is the thallus. Examine the end of each branch; what do you find there? Are the two forks into which the apex of the branches divides equal or unequal? Compare the growing end with the distal one; does it proceed from

a true root? Notice that as the lower end dies, the growing branches go on increasing and reproducing the thallus.

Do you find anything like a midrib? If so, trace it through the branches and body of the thallus; where does it end? Does it seem to be formed like the midrib of a leaf? Hold



FIGS. 475, 476. — Umbrella liverwort (*Marchantia polymorpha*): 475, portion of a female thallus about natural size, showing dichotomous branching; *f, f*, archegonial or female receptacles; *r*, rhizoids; 476, portion of a male thallus bearing an antheridial disk or receptacle, *d*, and gemmæ, *g, g*.

a piece of the thallus up to the light and see if you can detect any veins. Is it of the same color in all parts, and if there is a difference, can you give a reason for it? Examine the upper surface with a lens. Peel off a piece of the epidermis, place it under a low power of the microscope, or between two moistened bits of glass, and hold up to the light, keeping the upper surface toward you; what is its appearance?

Observe a tiny dot near the center of the rhomboidal areas into which the epidermis is divided and compare it with your drawings of stomata (181, 183).



FIG. 477. — A portion of the upper epidermis of *Marchantia*, magnified, showing rhomboidal plates with a stoma in each.

What would you judge that these dots are for? While differing in structure from the stomata of leaves, they serve the same purposes and may be regarded as a more rudimentary form of the same organ.

386. Rhizoids. — Wash the dirt from the under side of a thallus and examine with a lens; how does it differ from the upper surface? Do you see anything like roots? Place one in a drop of water under the microscope. Compare with similar organs found on the lichen (379). What are they? Would rhizoids be of any use on the upper side? stomata on the under side?

387. Gemmæ. — Look along the upper surface for little saucer-shaped (in *lunularia*, crescent-shaped) cupules (*g, g*, Fig. 476). Notice their shape and position, whether on a midrib or near the margin. Examine the contents with a lens and see if you can tell what they are. These little bodies, called *gemmæ*, are of the nature of buds, by which the plant propagates itself vegetatively somewhat as the onion and the tiger lily do by means of bulblets. Sow some of the *gemmæ* on moist sand, cover them with a tumbler to prevent evaporation, and watch them develop the thalloid structure.

388. The fruiting receptacles. — Procure, if possible, thalli with upright pedicels bearing flattened enlargements at the top (Figs. 475, 476). These are thallus branches modified into receptacles containing the reproductive organs, which, in *Marchantia*, are dioecious, the two kinds growing on separate thalli. Notice their difference in shape, one kind being slightly lobed or scalloped, the other rayed like the spokes of a wheel. The first kind are known as *antheridial*, or male, receptacles; the second as *archegonial*, or female,

389. The antheridia. — Examine one of the male receptacles on both surfaces and in vertical section. Notice the tiny egg-shaped bodies sunk in little cavities between the lobes just under the upper epidermis (Fig. 478). These are antheridia. When mature, they rupture at the apex, and multitudes of extremely small bodies, called *antherozoids*, or *spermatozoids*, are discharged from them.

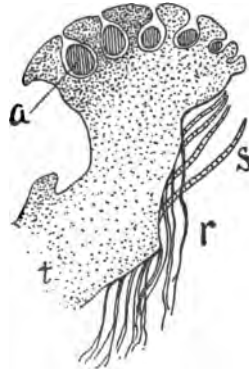


FIG. 478. — Longitudinal section of a male receptacle of *Marchantia polymorpha*, magnified: *a*, antheridia; *t*, thallus; *s*, ventral scales; *r*, rhizoids.



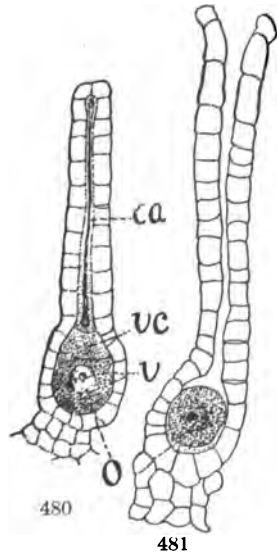
FIG. 479. — Under side of an archegonial receptacle enlarged. The archegonia are borne among the hairs on the under surface, which is presented to view in the figure; *f*, a spore case.

390. Archegonia. — Next examine one of the female receptacles. Look on the under surface, between the narrow divisions of the receptacle, for radiating rows of flask-shaped bodies with their necks turned downward, and all surrounded by a toothed sheath or involucre (Fig. 479). These bodies are the archegonia, or female organs, and correspond, loosely speaking, to the ovaries of flowering plants. If the receptacle is a mature one, the archegonia will be replaced by the ripe spore cases (*sporangia*), as at *f*, Fig. 479.

Make enlarged drawings of the upper surface of a male and a female receptacle, and of a vertical section of each, passing through an antheridium in the male, and an archegonial row in the female receptacle. Label the parts observed in each.

391. Minute study of an archegonium. — Place under the microscope a very thin, longitudinal section through a ray of a receptacle containing a young archegonium, and observe that the latter consists of a lower portion, the *venter*, *v*, Fig. 480, and an

upper part, the neck, which is perforated by the *neck canal*, *ca*. The venter contains the *egg cell*, *o*, and the ventral canal cell, *vc*. The neck canal is filled with small cells which, at maturity, dissolve into a mucilaginous substance that swells on being wet and discharges itself through the top of the neck, leaving an open passage to the venter, where the egg cell is ready to be fertilized.



FIGS. 480, 481. — 480, young archegonium of *M. polymorpha*; *v*, ventral portion; *o*, egg cell; *vc*, ventral canal and cells; *ca*, neck canal with cells; 481, the same ready for fertilization after discharge of the mucilaginous fluid.

Make a drawing of the section as seen under the microscope, labeling all the parts.

392. Fertilization. — In the liverworts, and in cryptogams generally, this process has to take place under water, as the antherozoids are motile only in a liquid, but the amount required is so small that a few drops of rain or dew will enable them to make their journey to the archegonium. The mucilaginous substances discharged from the neck canal attract them to the mouth of the opening, one or more of them penetrates to the egg cell, and fertilization is accomplished. Do you see any analogies between this and the same function among flowering plants? (250, 251.)

393. The spore case. — After fertilization the egg becomes an *oöspore*, capable of producing a new plant. Instead, however, of separating from the mother plant and giving rise to an independent growth, it germinates within the archegonium and produces there a small, stalked body, called a *sporogonium*, or *sporophyte*, which at length ripens into a spore case, as shown at *f*, Fig. 479. At maturity this capsule-like sporophyte ruptures at the apex, and discharges

a mass of spores, mingled with elongated filaments called *elators*, which, by their elastic movements, assist in disseminating the spores. These latter, on germinating, produce, not a simple sporophyte like that which bore them, but the thallus of the liverwort with all its complicated arrangement of antheridia and archegonia and vegetative organs that seem to foreshadow, by the analogies they suggest, the coming of the higher plants.

394. Sexual and asexual reproduction. — We find here a very marked change from the simple reproductive processes observed in the algæ and fungi. In the forms thus far considered, this function was carried on mainly by simple vegetative fission or budding, with a more or less irregular intervention of resting spores. If only one kind of spore is concerned, reproduction is said to be *asexual*. When two different kinds of cells, the egg and sperm cell, unite to form an oöspore, as in the liverworts, reproduction is said to be *sexual*. While sexual reproduction takes place to some extent among both algæ and fungi, the prevailing method among thallophytes is asexual, and may be carried on in three different ways: by fission (and budding), by resting spores, and by conjugation.

Representing the plant body by A and the resting spores by a , the primitive asexual processes may be expressed to the eye by the accompanying formulas:—

(1) Fission and budding: $A \rightarrow A \rightarrow A \rightarrow A \rightarrow$

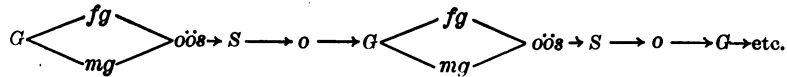
(2) Resting spores: $A\ a \rightarrow A\ a \rightarrow A\ a \rightarrow$

(3) Conjugation: $A + A \rightarrow a \rightarrow A + A \rightarrow a \rightarrow$

In (3), as was seen in the conjugating cells of the *spirogyra* (342), the method is a little more complicated, showing an approach toward the sexual process. In each of these cases, however, there is only one kind of cell concerned, while in the liverworts there are not only different kinds, technically known as *gametes*, but specialized organs, archegonia and antheridia, for producing them. The thallus body bearing these organs is termed the *gametophyte*, because it

bears the gametes, or sexual organs, — the suffix *phyte* meaning a plant ; for example, *epiphyte*, on or upon plants ; *spermo-phyte*, or *spermatophyte*, seed plant ; *sporophyte*, spore plant. The *sporophyte*, produced within the archegonium, bears simple nonsexual spores that are capable of germinating independently. Structurally it is a separate, individual organism, though it does not appear as such in this class, but lives inclosed in the archegonium, as a parasite on the mother plant.

395. Alternation of generations. — If we represent the sporophyte by *S*, the thallus, or gametophyte, by *G*, the female gamete, or egg cell, by *fg*, the antherozoids (male gametes) by *mg*, the fertilized egg cell, or oöspore, resulting from their union by *oös*, and the asexual spores discharged from the sporophyte by *o*, this complicated mode of reproduction may be expressed diagrammatically as follows :—



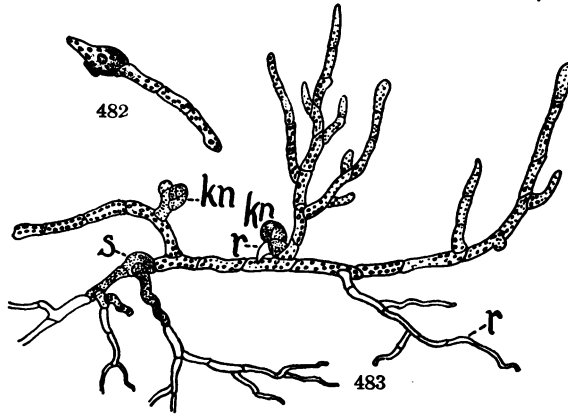
A glance at the diagram will show a continual interchange of the sexual and asexual modes of reproduction, in which each generation gives rise to its *opposite*, the asexual sporophyte producing the sexual gametophyte, and this in turn, through its gametes, giving rise to the asexual sporophyte. This regular recurrence in genealogical succession of two differing forms is what is meant by the expression “ alternation of generations.” Analogous processes occur also among some of the thallophytes, but as there is no well-defined differentiation of sporophyte and gametophyte, alternation proper may be regarded as beginning with the bryophytes. The subject is a complicated one and somewhat difficult to grasp, but it is important to form a correct idea of it and to fix clearly in mind the different modes of reproduction as we proceed from the lower to the higher forms of vegetation, since in this way alone can their biological

relationships and their order of succession in the evolutionary scale be made intelligible.

VI. MOSSES

MATERIAL. — One of the most widely distributed of mosses is the *Sphagnum*, or peat moss, so generally used by florists in packing plants for shipment, and it can be obtained from them at almost all times. It is rather difficult, however, to find specimens with the fruiting organs, since they are rarely to be met with except in late autumn or early spring. Other common forms are *Polytrichum*, *Funaria*, and *Mnium*, any of which will meet all essential conditions of the study outlined in the text.

396. The protonema or thallus stage. — In mosses the sexual, or gametophyte, generation differs from that of liverworts in undergoing two phases. The germinating cells of the sporophyte do not develop immediately into the leafy stem, which is the typical gametophyte of true mosses, but produce first a filamentous, creeping structure



FIGS. 482, 483. — Protonema of a moss: 482, germinating spore; 483, protonema; *kn*, buds; *r*, rhizoids; *s*, spore.

called the *protonema* (Fig. 483), that spreads over the ground and forms the tangled green felt usually observed where mosses are growing. Place a few of these filaments on a slide in water, and examine under the microscope. Do they remind you of any of the forms of algæ? Look near

the base of the branches for knots or enlargements, like those seen at *kn*, Fig. 483. These are buds from which the leafy moss stems will develop. Do they correspond to anything observed among the thallophytes? Notice the rootlike filaments that extend under ground; how do they differ from the ones above ground? Why are they colorless? How do you know that they are not true roots? [67 (*a*), 379.] Sketch one of each kind of filament sufficiently enlarged to show the cells composing it.

A protonema that arises directly from the spore is said to be *primary*, while those which sometimes spring from rhizoids above ground, or from stems or leaves, are *secondary*. The fact that a protonema can bud from parts of the fruiting stems shows that the two do not belong to different generations, but are merely successive stages of a single generation, and both together compose the gametophyte.

397. The leafy stage.— In their fully developed state the true mosses show a marked advance in organization over



FIG. 484. — *Scapania*, a liverwort with leafy thallus, approaching the form of mosses and lycopodiums. (From COULTER'S "Plant Structures.")

the liverworts. There is a distinct differentiation of the growing axis into stem and leaves, though no true roots are formed. The leaves are arranged spirally, on upright stems, while in the liverworts the vegetative body is either a flat, spreading thallus, or the leaves are arranged horizontally on opposite sides of a prostrate, or more or less inclined, axis. Sometimes a second set occurs, on the upper side of the axis, but in this case the leaves are usually much smaller and inclined to the horizontal arrangement, as shown in Fig. 484.

398. The reproductive organs.— The antheridia and archegonia are borne in groups at the end either of the main

axes, or of lateral branches (Figs. 485, 486), but as a rule only one archegonium is fertilized, so the mature sporogonia are solitary. The plants may be either dioecious or monœcious, as

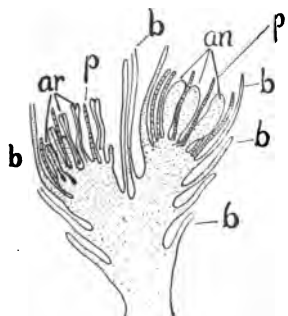


FIG. 485. — Fruiting receptacle of a moss (*Phascum cuspidatum*), bearing both antheridia, *an*, and archegonia, *ar*, at the bifurcated apex; *b*, leaves; *p*, paraphyses.

in Fig. 485; and in the latter case, the reproductive organs may be borne on the same, or on different, receptacles. The antheridia and the archegonia are both mixed with club-shaped hairs called paraphyses (Fig. 485).

399. The sporophyte. — An examination of the fruiting capsule of any of the true mosses will show that it consists of a long footstalk, the *seta*, *s*, Fig. 486, bearing a capsule, or ripened sporogonium, *f*, which is at first surmounted by a cap or hood, known as the *calyptra*, *c*. The hood represents the excessively developed and often highly specialized wall of the archegonium. It falls away at maturity, and the spores are discharged through an opening made by the removal of the *operculum*, or lid, *d*. The spores and the capsule are both developed from the fertilized egg (oöspore), within the archegonium, in much the same manner as in the liverworts, and together constitute the sporophyte, or asexual generation. It never leads a completely independent existence, but remains a partial parasite on the mother plant, though the lower part of the young sporogonium is usually provided with stomata



FIG. 486. — Fruiting stem of a moss (*Polytrichum commune*) with ripe capsules: *s*, seta, or footstalk; *c*, capsule with calyptra; *f*, capsule after the calyptra has fallen away; *d*, operculum, or lid.

and chlorophyll so that it is capable of manufacturing food. In this respect it shows a distinct advance on the corresponding phase of the liverworts—if we except the single genus *Anthoceros*, which alone among the liverworts has the cells of the sporogonium provided with chlorophyll.

400. Alternation of generations. — The process of reproduction in mosses is so closely similar to that of liverworts that it is unnecessary to repeat the details. There are some minor variations, but in all essentials the processes are the same and may be represented to the eye by the same formula.

401. Relative position of mosses and liverworts in the line of evolution. — Though mosses, as a rule, show a higher degree of organization than liverworts, in both generations, their development has been *away* from the general course of evolution followed by the higher plants. This, as will be seen later, tends towards a decreasing complexity of the gametophyte with increasing complexity of the sporophyte, while the mosses show increasing complexity of *both*. Like the order of birds in the animal kingdom, they form a highly specialized and somewhat isolated group. While they may be regarded as descendants from a common ancestral stock with the ferns and club mosses, they have been switched off, so to speak, on a side track of the great evolutionary trunk line, and their advance on this side track has carried them to a point more remote from the course along which the higher forms of plant life have traveled than the distant junction at which they branched off from their less progressive kindred, the humble liverworts.

VII. FERN PLANTS

MATERIAL. — Any kind of fern in the fruiting stage. Several different varieties should be cultivated in the schoolroom for observation. While gathering specimens, look along the ground under the fronds, or in greenhouses where ferns are cultivated, among the pots and on the floor, for a small, heart-shaped body like that represented in Figs. 501, 502, called a *prothallium*. It is found only in moist and shady places, and care should

be taken in collecting specimens, as in their early stages the prothallia bear a strong resemblance to certain liverworts found in the same situations. The best way is for each class to raise its own specimens by scattering the spores of a fern in a glass jar, on the bottom of which is a bed of moist sand or blotting paper. Cover the jar loosely with a sheet of glass and keep it moist and warm, and not in too bright a light. Spores of the sensitive ferns (*Onoclea*) will germinate in from two to ten days, according to the temperature. Those of the royal fern (*Osmunda*) germinate promptly if sown as soon as ripe, but if kept even for a few weeks are apt to lose their vitality. The spores of sensitive fern can be kept for six months or longer, while those of the bracken (*Pteris*) and various other species require a rest before germinating, so that in these cases it is better to use spores of the previous season.

402. Study of a typical fern. — Observe the size and general outline of the fronds, and note whether those of the same plant are all alike, or if they differ in any way, and how. Observe the shape and texture of the divisions or pinnæ composing the frond, their mode of attachment to the rachis, and whether they are simple, or notched, or branched in any way. Hold a pinna up to the light and notice the veining. Is it like any of the kinds described in 171, 172? In what respect is it different? This forked venation is a very general characteristic of ferns. When the forks do not reticulate or intercross, the veins are said to be free; are they free in your specimen, or reticulated? Make a



FIGS. 487-491. — A fern plant: 487, fronds and rootstock; 488, fertile pinna: s, s, sori; 489, cross section of a stipe, showing ends of the fibrovascular bundles; 490, a cluster of sporangia, magnified; 491, a single sporangium still more magnified, shedding its spores.

sketch, labeling the primary branches of the frond, *pinnæ* (sing., *pinna*), the secondary ones, if any, *pinnules*, and the common stalk that supports them, *stipe*. Note the color, texture, and surface of the stipe. If any appendages are present, such as hairs, chaff, or scales (in *Pteris*, nectar glands), notice whether they are equally distributed. If not, where are they most abundant?

Examine the mode of attachment of the stipes to their underground axis. Break one away and examine the scar. Compare with your drawings of leaf scars and with Fig. 105. Do the stipes grow from a root or a rhizome? How do you know? Do you find any remains of leafstalks of previous years? How does the rootstock increase in length? Measure some of the internodes; how much did it increase each year? Cut a cross section and look for the ends of the fibrovascular bundles. Trace their course through several internodes. Do they run straight, or do they turn or bend in any way at the nodes? If so, where do they go? Do you see anything like roots? Where do they originate? Put one of them under the microscope and find out whether they are roots or hairs.

True roots are first developed in the pteridophytes. Since those of the fern spring from an underground stem, to what class of roots do they belong? (83.)

403. Minute study of a fern stem.—Place a very thin section of a fern rhizoma, or of the stipe of a frond, under the microscope. Except in very young stems the vascular bundles are arranged in a ring, or sometimes in two or more rings (Fig. 492), with plates of strengthening tissue, *l, l*, between the inner and outer rings. Notice the inner epidermal layer of hard brown tissue, and within that, the soft parenchyma, which fills the rest of the interior. Test it with iodine and observe how rich in starch it is. If the section of a petiole is under observation, the details will be somewhat different; would you expect to find as much starch in the stipe as in the rootstock? Why, or why not?

Make a longitudinal section of a rhizome through the point where a leafstalk is attached and trace the course of the bundles. This will be facilitated if the specimen has stood in eosin solution a few hours. Make enlarged drawings of both sections, labeling all the parts.

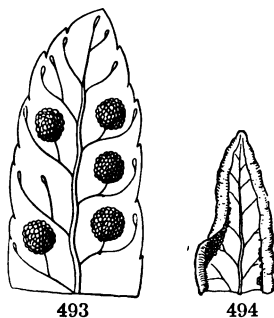
Clearly differentiated conducting bundles occur in the mosses, but they are of much simpler structure than in the pteridophytes, consisting usually of a single central strand, and are

FIG. 492. — Diagram of a cross section through the stem of a fern (*Pteris*): *s, s, s*, rings of fibrovascular bundles; *l, l*, plates of strengthening tissue, with a ring of fibrovascular bundles between them; *lp*, zone of strengthening fibers; *r*, cortex; *e*, epidermis.

found more frequently in the leaves than in the stems. A true vascular structure appears first in the pteridophytes, whence these plants are distinguished as *vascular cryptogams*.

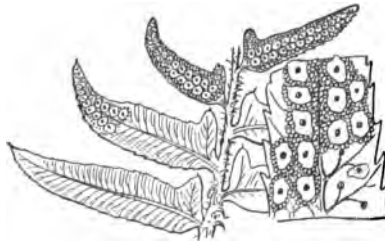
404. Fructification. — Examine the back of a fruiting frond; what do you find there? These dots are the *sori* (sing., *sorus*), or spore clusters, and the fronds or pinnæ bearing them are said to be *fertile*. Are there any differences of size, shape, etc., between the fertile and the sterile fronds of your specimen?

between the fertile and the sterile pinnæ? On what part of the frond are the fertile pinnæ borne? Notice the shape and position of the sori, and their relation to the veins, whether borne at the tips, in the forks, on the upper side



FIGS. 493-494. — Parts of fertile pinnæ: 493, of *polypodium*, enlarged, showing the sori without indusium; 494, of *ptelea*, showing indusium formed by the revolute margin.

(toward the margin), or the lower (toward the midrib). Look for a delicate membrane (*indusium*) covering the sori, and observe its shape and mode of attachment. If the



FIGS. 495-496. — Christmas fern (*Aspidium*): 495, part of a fertile frond, natural size; 496, a pinna enlarged, showing the sori confluent under the peltate indusium.

specimen under examination is a polypodium, there will be no indusium; if a maiden-hair, or a bracken, it will be formed of the revolute margin of the pinna. In lady fern and Christmas fern (*Aspidium*), the sori frequently become confluent, that is, so close together as to appear like a solid mass. Sketch a

fertile pinna as it appears under the lens, bringing out all the points noted.

405. The spore cases. — Look under the indusium at the cluster of little stalked circular appendages (Fig. 490). These are the *sporangia*, or spore cases, in which the reproductive bodies are borne. Place one of them under the microscope, and it will be found to consist of a little stalked circular body like a tennis racket (Fig. 491), surrounded by a jointed ring called the *annulus*. Watch a few moments and see if you can find out the use of the annulus. If not, warm the



497



498



499



500

FIGS. 497-500. — Spores of pteridophytes, magnified: 497, a fern spore; 498, 499, two views of a spore of a club moss; 500, spore of a common horsetail (*Equisetum arvense*).

slide and you will probably see the ring straighten itself with a sudden jerk, rupturing the wall of the sporangium and discharging the spores with considerable force. If this does not happen, add a drop of strong glycerine to a specimen mounted in water; the rupture will be apt to follow quickly. What causes it, in either case? [56, (1); Exp. 19.]

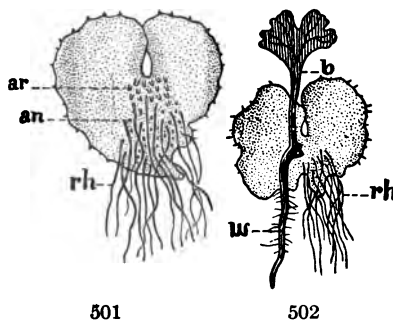
406. The sporophyte. — The spores found in such abundance on the fertile pinnæ are all alike, and each one is capable of germinating and continuing the work of reproduction as effectually as the sexual spores of the bryophytes. The fertile frond, or part of a frond, on which they are borne is called a *sporophyll* (spore-bearing leaf), and the entire plant is the *sporophyte*, which, with its crop of spores, makes up one generation.

It is important to observe that in the ferns and in all pteridophytes the sporophyte is the conspicuous and highly organized body that is commonly recognized as the normal growing plant; while with the bryophytes just the reverse holds true, — the sexual generation, or gametophyte, represents the normal plant structure, while the sporophyte is an insignificant appendage which never attains an independent existence. Broadly speaking, in bryophytes, it is a spore fruit; in the pteridophytes and spermatophytes a highly developed plant.

407. The gametophyte.

— When one of these asexual spores germinates, it produces, not a fern plant like the one that bore it, but a small, heart-shaped

body like that shown in Fig. 501. Examine one of these bodies carefully with a lens. Observe that there are no veins nor fibrovascular bundles, and the whole body of the plant seems to consist of one uniform tissue. Compare it with the forked apex of a branching thallus of a liverwort. Do you perceive any points of similarity? The two are, in fact, morphologically the same. This heart-shaped body is called a *prothallium*, and is the gametophyte of the fern. It may be of



FIGS. 501, 502. — Prothallium of a common fern (*Aspidium*): 501, under surface, showing rhizoids, *rh*, antheridia, *an*, and archegonia, *ar*; 502, under surface of an older gametophyte, showing rhizoids, *rh*, young sporophyte, with root, *w*, and leaf, *b*.

different shapes, and in some species is branching and filamentous, like the protonema of a moss. Generally, however, it is flat and more or less two-lobed, as shown in Fig. 501. It is small and inconspicuous and very short-lived, being of importance only in connection with the work of reproduction.

Look with your lens for a cluster of small, bottle-shaped bodies just below the deep cleft in the heart. If you cannot make out what they are, put a thin section through a part of the prothallium containing one under the microscope, and you will see that they are the archegonia. Lower down among the rhizoids, near the pointed base, will be found the antheridia. In some species the prothalli are dioecious, one kind bearing antheridia, the other archegonia, but this is rare among the true ferns.

408. Fertilization. — This process is the same in all essentials as in the bryophytes. As in other cryptogams, it can

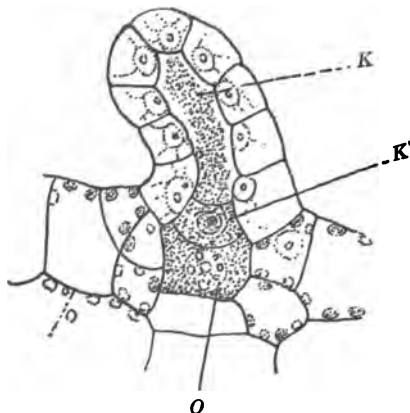


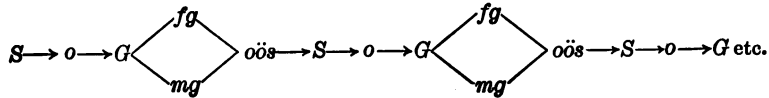
FIG. 503. — Young archegonium of a fern, magnified: *K*, neck canal cell; *K'*, ventral canal cell; *O*, egg cell.

take place only under water, — a circumstance which points to an aquatic origin for this subkingdom, and through them to the entire flora of the globe. The archegonia differ somewhat in shape from those of the liverworts and mosses, but a section under the microscope will show that they consist of essentially the same parts. On account of the similarity of these organs, the pterido-

phytes and bryophytes are often classed together as *Archegoniates*.

409. Alternation of generations. — Among the section of ferns that we have been considering, the order of alternation corresponds in all essentials to that prevailing among the

bryophytes, and may be represented by the same formula. The chief difference is in the relatively much greater importance of the sporophyte, which may be expressed by putting it first: —



But some of the pteridophytes — of which the *Selaginella* offers a conspicuous example — have differentiated their

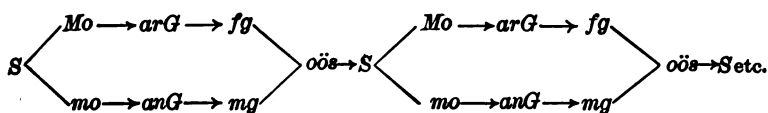


FIGS. 504–508. — A kind of pteridophyte (*Selaginella martensii*) with its organs of fructification: 504, a fruiting branch; 505, a microsporophyll with a microsporangium, showing microspores through a rupture in the wall; 506, a megasporophyll with a megasporangium; 507, megaspores; 508, microspores. (From COULTER'S "Plant Structures.")

asexual spores (*o* of the formula) into two kinds, large and small, known respectively as *megaspores* and *microspores*. The prothallia developed by the former bear archegonia containing female gametes only; those by the latter, antheridia containing male gametes — while in the dioecious bryophytes, the archegonial and antheridial thalli are produced by spores of the same kind.

The differentiation of the asexual spores in the higher pteridophytes gives rise to corresponding changes in the sporangia that bear them, and even in the sporophylls themselves, one kind bearing microsporangia only, the other megasporangia. In this way the differentiation of sex is pushed back, step by step, until it virtually begins with the sporophyte, or asexual generation.

Using the same terms as before, and representing the microspores by the abbreviation *mo*, the megaspores by *Mo*, the archegonial gametophyte by *arG*, the antheridial by *anG*, the formula may be modified to express this more complicated process of alternation, as follows: —



Comparing this formula with the preceding, it will be seen that the increased complexity affects the sporophyte at the expense of the gametophyte, which has now become a mere dependent on the former.

410. Advantages of alternation. — This roundabout mode of reproduction would hardly have been developed unless it had been of some benefit to the plants in which it occurs. The chief advantage seems to be in more rapid multiplication and consequently better chance to propagate the species, as compared with the slow process of sexual reproduction were the plant confined to that method alone. Only one plant is produced by each oöspore, and if this were a gametophyte with its limited number of archegonia, multiplication would

be slow ; but the sporophyte with its millions of spores, each capable of producing a new individual, enables the species to multiply indefinitely. At the same time the interposition of a gametophyte, or sexual generation, secures the introduction of a new strain with effects analogous to those of cross fertilization.

411. Classification of pteridophytes. — In our study of this group, the ferns have been taken as the type because they are the most familiar and most widely distributed of all the vascular cryptogams. But while they exceed in numbers, both of individuals and species, all the other orders combined, they form only one division of three great groups that make up the class Pteridophyta. These groups are: (1) ferns, under which are included, besides the true ferns, two widely differing orders, with the grape ferns and adder's-tongue in one, and the water ferns in the other; (2) the club mosses, embracing the two subdivisions of *Lycopodium* and *Selaginella*; (3) the horsetail family, including horsetails and scouring rushes. Orders (2) and (3) are grouped together as cone-bearing (strobilaceous) pteridophytes, because their sporangia are clustered in oblong heads, or *strobiles* (Fig. 509), somewhat like the cones of the pine. The orders of pteridophytes differ greatly among themselves, but agree in possessing certain characteristics that point to their derivation from a common ancestry.

412. Distinction between pteridophytes and bryophytes. — In passing from the Thallophytes and Bryophytes to the vascular cryptogams, we cross the widest chasm in the vegetable kingdom — a gap relatively as great as that between vertebrates and invertebrates among animals. The most important modifications that discrimi-



FIG. 509. — Part of the fruiting stem of a scouring rush, *Equisetum limosum*, showing the cone-like spore cluster. (After GRAY.)

nate the two groups are: (1) the presence in Pteridophytes of a highly organized vascular system accompanied by a well-marked differentiation of the plant body into root and stem; (2) increased importance and complexity of the sporophyte with proportionate diminution of the gametophyte.

While vessels for conducting water occur in some of the bryophytes (403), a well-defined vascular system and true roots are met with first in the Pteridophytes. The change in the relative importance of sporophyte and gametophyte is so marked that in *Selaginella*, the genus which approaches nearest in structure to the seed-bearing plants, the suppression of the gametophyte has proceeded so far that it never leads an independent existence at all and is difficult even to recognize as a distinct individual.

Practical Questions

1. Have ferns any economic use — that is, are they good for food, medicines, etc.?
2. What is their chief value?
3. Under what ecological conditions do they grow?
4. Are they often attacked by insects, or by blights and disease of any kind?
5. Of what advantage is it to ferns to have their stems underground, in the form of rootstocks? (321.)
6. What causes the young frond of ferns to unroll? (54, 98.)
7. Name the ferns indigenous to your neighborhood.
8. Which of these are most ornamental, and to what peculiarities of structure do they owe that quality?
9. Are cultivated ferns usually raised from the spores or in some other way? Why?
10. After the great eruption of Krakatao in 1883, by which the vegetation of the island was completely destroyed, ferns were the first plants to reappear. Explain why. (19; Exp. 17.)

VIII. THE RELATION BETWEEN CRYPTOGRAMS AND SEED PLANTS

413. No break in the chain of life. — The great gap that was once supposed to exist between the cryptogams and phanerogams has been bridged over by the discovery of

analogies in the reproductive processes of the two groups that connect them together as successive links in one continuous chain of vegetable life. It is therefore very important to have a clear understanding of the nature and meaning of these processes, for the chief turning points in the life history of the different groups of plants are connected with them, their natural relationships to each other, and their distribution according to their respective places in the evolutionary scale, being determined largely by a comparison of their modes of continuing the life of the group.

414. Alternation of generations in seed plants. — This process, so conspicuous among Bryophytes and Pteridophytes, and not unknown among Thallophytes, is universal among seed plants (Spermatophytes) also, though in so masked a form that it is not easy to recognize without a more detailed study than would be practicable within the limits of a book like this. Briefly, we may say that the stamens of spermatophytes, and the pistils, or rather the carpels, which we have seen to be transformed leaves (298), represent the sporophylls (406) of the higher pteridophytes. The pollen sacs and ovules are sporangia, bearing microspores and megaspores (409), represented respectively by the pollen grains in the anther and the embryo sac in the ovule. These go through a series of microscopic changes in the body of the ovule analogous to the production of the oöspore in the archegonia of ferns and liverworts, but the process is so obscure that to an ordinary observer the pollen grains and the ovule appear to be the real gametes, and were long supposed to be such. The fertilized germ cell in the embryo sac (251) corresponds to an oöspore; the embryo sac with the endosperm found in all seeds (previous to its absorption by the cotyledons) is a rudimentary gametophyte; and the embryo in the matured seed is the undeveloped sporophyte, destined, after germination and further growth, to produce a new generation with its recurrent cycle of alternating phases.

In the gymnosperms, — pines, yews, cycads, etc., — which represent the most ancient and primitive type of existing

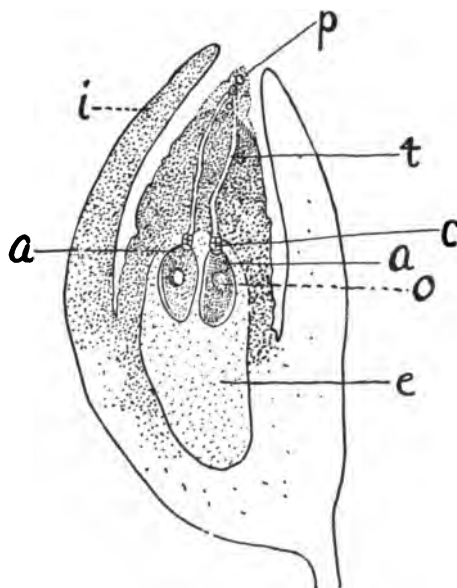


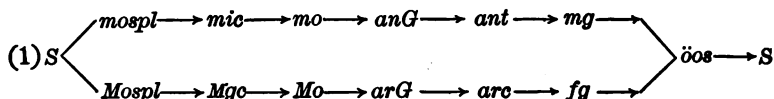
FIG. 510. — Diagrammatic section through the ovule of a gymnosperm belonging to the spruce family: *i*, integument covering the ovule; *e*, endosperm (corresponding to female gametophyte), which fills the embryo sac, containing two archegonia, *a*; *o*, egg cell; *p*, pollen grains; *t*, pollen tubes entering the neck, *c*, of the archegonia.

seed-bearing plants, the similarity of these processes to those of certain of the pteridophytes is very striking, and it was through the study of these that the sequences of the process were traced in the much more obscure form in which they occur among the angiosperms. From the endosperm in the seeds of gymnosperms archegonia were found to be developed (Fig. 510) in much the same way as in *Selaginella*, from the prothallium, thus showing the endosperm to be a modified and greatly reduced

gametophyte. In some cases, it has even been found to protrude a little way out of the embryo sac and to take on a slightly greenish tinge — another reminiscence of its origin. Fertilization, too, takes place in precisely the same manner as in the pteridophytes, except that in all but the ginkgo and the cycads, the fertilizing cells in the pollen grains are non-motile, and find their way to the ovule by growing down into the embryo sac with the pollen tube, instead of swimming to it — an adaptation probably brought about in response to changed conditions during the course of evolution from aquatic to terrestrial life.

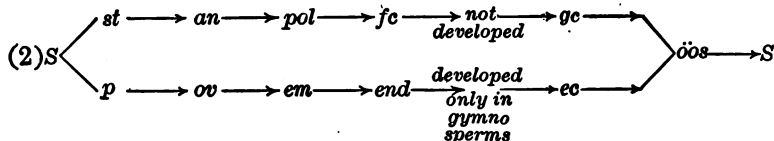
The analogies between the sequence of alternations in the two classes will be made clearer by a comparison of the accompanying diagrams. The corresponding terms applied to the various organs stand in the same vertical row. Diagram (1) shows the process as it takes place in the more highly developed Pteridophytes; diagram (2) the corresponding phases in angiosperms.

PTERIDOPHYTES



mospl, microsporophyll; *mic*, microsporangium; *mo*, microspores; *anG*, male gametophyte; *ant*, antheridia; *mg*, antherozoids. The letters in the lower line stand for the corresponding female organs.

SPERMATOPHYTES



st, stamen; *an*, anther; *pol*, pollen; *fc*, food cells in pollen grain; *gc*, generative cell; *p*, pistil; *ov*, ovules; *em*, embryo sac; *end*, endosperm; *ec*, egg cell.

415. Disappearance of the gametophyte. — The seed is a comparatively recent development in plant evolution. It has no counterpart anywhere among the cryptogams, but is strictly characteristic of the three great orders of Spermatophytes: Monocotyl, Dicotyl, and Gymnosperms, which compose the greater part of the vegetation of the globe. Structurally, it is a matured sporangium containing a rudimentary sporophyte (the embryo), and a reduced gametophyte (the embryo sac), which, under the form of endosperm, has dwindled to an insignificance that makes it difficult to recognize it as a phase in an alternation of generations.

416. Significance of the sporophyte. — The gametophyte is obviously a more ancient and primitive structure than the sporophyte, which first becomes prominent in the ferns and

their allies. The sudden and violent break in the succession of vegetable life that accompanies the appearance of the pteridophytes (412) is probably to be explained by the development of a land flora and the necessity of adaptation to life in a new medium. The fact that no living cell, whether vegetable or animal, can absorb nourishment except in a liquid form, seems to point to an aquatic origin more or less remote for all life. This inference is further strengthened, in the case of plants, by the fact that even in so highly organized a group as the pteridophytes, fertilization cannot take place except in water. Such a requirement would manifestly be a great disadvantage to land plants, and one of the first steps in response to the demands of a new habitat would be to get rid, as far as possible, of the primitive gametophyte with its outgrown adaptations to a liquid medium, and to transfer the greater part of the work of reproduction to the asexual generation, in which the problem of fertilization did not have to be directly met, the asexual spores germinating without it. The greater the number of these produced, the better the chance that at least some of the gametes developed from them would meet the difficult conditions of fertilization, and the survival of the species be assured. At the same time, in order to meet the requirements of terrestrial life successfully, and to provide for continuing the sexual generation, correlative changes would have to take place in the gametophyte by which the increasing uncertainty of fertilization due to structural changes in the sporophyte, and the absence of a liquid medium for the conveyance of free swimming antherozoids would be avoided. This necessity has been met by the development of the pollen tube, which bores its way to the egg cell, carrying with it the generative cells, which in seed plants have taken the place of the more primitive antherozoids. With the concomitant reduction of the gametophyte and development of the seed habit, the adaptation to land conditions has been made complete.

Roughly speaking, it may be said: (1) that Thallophytes are predominantly aquatic; (2) Archegoniates (Bryophytes and Pteridophytes), amphibious; (3) Spermatophytes, terrestrial; (4) that the seed habit is a response to terrestrial conditions; and (5) that the increased development of the sporophyte was a necessary adaptation to meet those conditions.

IX. THE COURSE OF PLANT EVOLUTION

417. Plant genealogy. — It has been shown by a study of existing forms of plant life that there is no hard and fast line of division anywhere between the different groups, but that they are all connected by ties of kinship more or less defined, according to their distance from a common ancestral stock. The geological record points to the same conclusion, and our classification of them into families, orders, and species is merely a very imperfect genealogical table of their supposed pedigrees. This does not mean, however, that we can assert positively that such and such a species is derived from such or such another, but that both are descended from some common intermediate form more or less remote. While we have reason to believe that the flowering plants are derived through pteridophyte and bryophyte types from some of the green algæ, no direct connection has ever been traced between any particular kind of flowering plant and any particular kind of alga, — or between a liverwort and an alga, for that matter, — and probably never will be, because the intermediate forms die out, or pass on by variation into other lines of development. But while this is true, all the evidence we possess does go to show that, since the beginning of life on the globe, there has been a general progressive evolution from lower and simpler to higher and more complex forms.

418. Retrogressive evolution. — While the general course of evolution has been upward and onward, the movement has not always followed a straight line, but, like a mountain road,

shows many windings and deviations from the direct route. The monocotyls furnish a conspicuous example of this departure from the general law of progression. It was formerly supposed, on account of their greater simplicity of structure, that they were a more ancient type than dicotyls, but recent investigations point to the conclusion that they are a later offshoot, derived from some primitive form of aquatic dicotyl, and represent, not an ancient and primitive stock, but a case of retrogressive evolution from a higher type. Strong presumptions in favor of this view are: (1) that various species of dicotyls show an unequal development of the seed leaves, amounting, in the bryony, to complete abortion of one of them, while some monocotyl seeds show morphological characters that can best be explained as survivals, or inheritances, from a dicotyl ancestor; (2) the structural resemblances between gymnosperms and dicotyls are closer than between gymnosperms and monocotyls, which could hardly be the case if the latter were the more ancient; (3) the geological record does not show them to have appeared before dicotyls; (4) the number of cotyledons furnishes no criterion as to the relative age of any plant group, since all three types are represented among the pteridophytes, where plants are found bearing one, two, or more cotyledons.

The theory of their comparatively recent origin from an aquatic ancestor is further borne out by the many points of similarity between their internal structure and that of hydrophytes (318), and also by the great proportion of aquatic plants among them, amounting to thirty-three per cent, while in dicotyls the proportion is only four per cent. Can you give any reasons, from your examination of their internal structure (113, 114), for believing that the line of development which they have followed is a less effective one for meeting conditions now existing on the globe than that attained by dicotyls?

We should remember, too, that while progressive evolution implies successful adjustment to surroundings, it is possible

to conceive of a state, as our planet approaches the period of cosmic debility and decay, when the conditions of existence may become progressively more and more unfavorable. In this case the course of evolution would be reversed, the higher types gradually dying out as the struggle for life became more severe, and the tendency would be constantly toward lower and simpler forms, until finally all life would become extinct on our planet.

We have no right, however, to assume that during such a course of retrogressive evolution the same forms would be repeated in reverse order as have already appeared, because there is no reason to believe that the conditions brought about by planetary decline and "old age" would be the same as those attending planetary birth and adolescence.

419. Explanation of the diagram.

— An attempt to show the general course of plant

evolution up to the present time is made in the accompanying diagram. The four great divisions, Thallophytes, Bryophytes, Pteridophytes, and Spermatophytes, are represented by spaces between four horizontal lines arranged one above the other in the order of their succession in time and complexity of organization. It should be borne in mind that these dividing lines are not sharply defined in nature, but overlap or indent the territory between them with vary-

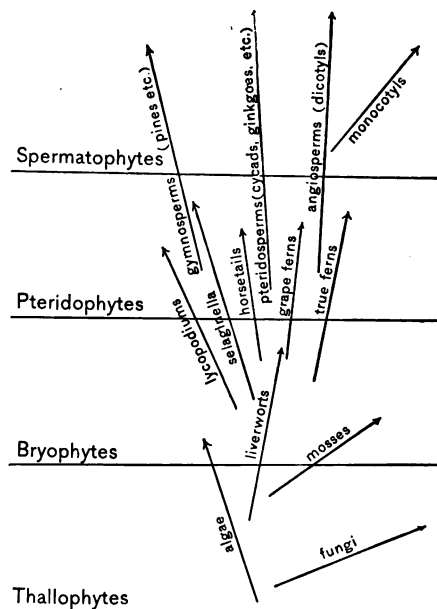


FIG. 511. — Diagram showing the supposed course of plant evolution.

ing degrees of irregularity, like the coast line on a map. The relative positions of the different orders we have been considering are represented by upright and diagonal lines, the general course of which, as indicated by the arrows, is intended to give an idea of the trend of evolutionary progress in the particular group represented by each line. No one of these lines is made to originate directly in any other, because, with the possible exception of the monocotyls, we have no authority for asserting that any such direct connection exists between plants as we know them, but only that certain types give evidence of descent from a common ancestry. This lack of certainty is expressed by placing the point of origin for any given line in more or less close proximity to the one which is supposed to be the nearest living representative of the common ancestor. The line of ferns, for instance, is depicted as originating in the region of the bryophytes, somewhere in the neighborhood of the liverworts, but the two lines nowhere come in contact, because there is no evidence that any fern, living or fossil, is directly descended from any particular kind of liverwort known to us. With these explanations, the diagram shows, in a rough way, the generally accepted view of plant relationships as based on the evidence at present before us. But in questions of this sort it is wise to keep in mind the blunt remark of a famous old American statesman, that "only fools and dead people never change their opinions."

Field Work

1. If you live in the country, study the appearance of plants affected with blights, smuts, rusts, and mildews, and learn to recognize the different kinds of disease by their signs. Notice which kinds are most prevalent in your neighborhood, and what plants are most affected by them.
2. Notice the different kinds of mushrooms you find growing wild. Observe the difference between those that grow on the ground and those that grow on logs, stumps, and trees; between those found in the woods and those in open ground. Find out how those on the ground get their nourishment. Uncover the mycelium, and notice the extent of its surface.

Examine the soil and find out if it contains anything upon which they could feed. Note the prevalence of shelf fungi on trees. Examine the condition of the wood where they grow, and decide in what ways they injure their hosts. Notice whether they abound most on healthy or on decaying trunks and boughs, and decide whether this is because the fungus prefers that kind of host, or whether the injury it does causes the decay, or whether both causes operate together. Notice what fungi grow on different trees, and study their preferences in this respect.

3. Observe the different kinds of lichens found in your walks and try to distinguish the three classes. Which kind are most abundant in your neighborhood? Which least so? Note the situations in which you find each kind growing, whether on stumps, trees, rocks, or the ground. Consider how the algæ and fungi aid each other in the different positions; could either, for instance, exist independently on bald rocks? Notice on what kind of trees the different lichens seem to thrive best and on which poorly or not at all, and whether the character of the bark — rough, smooth, scaly — has anything to do with their choice of a habitat.

APPENDIX

SYSTEMATIC BOTANY

Taxonomy, or systematic botany, deals with the family relationships of plants in the order of their nearness or remoteness with regard to a common line of descent. Its chief value is the insight it gives into the course of plant evolution and into the nature of the modifications that differentiate each group from the ancestral type. While it is not advisable to spend too much time in the mere identification of species, a sufficient number should be examined and described to familiarize the student with the distinctive characteristics of the principal botanical orders.

Principles of classification. — All the known plants in the world, numbering not less than one hundred and twenty thousand species of the seed-bearing kind alone, are ranged according to certain resemblances of structure, into a number of great groups known as families or orders. The names of these families are distinguished by the ending *aceæ*; the rose family, for instance, are the *Rosaceæ*; the pink family, *Caryophyllaceæ*; the walnut family, *Juglandaceæ*, etc. Each of these families is divided into lesser groups called *genera* (singular, *genus*), characterized by similarities showing a still greater degree of affinity than that which marks the larger groups or orders; and finally, when the differences between the individual plants of a kind are so small as to be disregarded, they are considered to form one species; all the common morning-glories, for instance, of whatever shade or color, belong to the species *Ipomea purpurea*. The small differences that arise within a species as to the color and

size of flowers, and other minor points, constitute mere varieties, and have no special names applied to them. The line between varieties and species is not clearly defined, and in the nature of things can never be, since progressive development, through unceasing change, is the law of all life.

In botanical descriptions, the name both of the species and the genus is given, just as in designating a person, like Mary Jones or John Robinson, we give both the surname and the Christian name. The genus, or generic name, answers to the surname, and that of the species to the Christian name — except that in botanical nomenclature the order is reversed, the generic, or surname, coming first, and the specific or individual name last; for example, *Ipomea* is the generic, or surname, of the morning-glories, and *purpurea* the specific one.

How to use the key. — Any good manual will answer the purpose. Gray's "School and Field Book" is, perhaps, the best available at present for the states east of the Mississippi. Reference to the floral analyses in sections I-IV of Chapter VII will make its use clear. Suppose, for instance, we want to find out to what botanical species the morning-glory or the sweet potato belongs. Turning to the key, we find the sub-kingdom of Phænerogams — flowering or seed-bearing plants — divided into two great classes, Angiosperms and Gymnosperms, as explained in 18. A glance will show that our specimen belongs to the former class. Angiosperms, again, are divided into the two subclasses of Dicotyledons and Monocotyledons (18, 171). We at once recognize our plant, by its net-veined leaves and pentamerous flowers, as a dicotyledon (171, 229), and turning again to the key, we find this subclass divided into three great groups: Sympetalous (211), called also Monopetalous and Gamopetalous; Apopetalous, or Polypetalous (211), and Apetalous — having no petals or corolla. A glance will refer our blossom to the sympetalous or monopetalous group, which we find divided

into two sections, characterized by the superior or inferior ovary (218, 225). Further examination will show that the morning-glory belongs to the former class, which is in turn divided into two sections, according as the corolla is *regular*, or *more or less irregular*. We see at once that we must look for our specimen in the group having regular corollas. This we find again subdivided into four sections, according to the number and position of the stamens, and we find that the morning-glory falls under the last of these, — “Stamens as many as the lobes or parts of the corolla and alternate with them.” A very little further search brings us to the family *Convolvulaceæ*, and turning to that title in the descriptive analysis, we find under the genus, *Ipomea*, a full description of the common morning-glory, in the species *Ipomea purpurea*, and of the sweet potato in the species *Ipomea batatas*.

Making collections. — Mere labeled aggregations of species are not recommended, but the collection of examples illustrating special points in morphology and plant variation may be made with profit; such, for instance, as the adaptations observed in tendrils and stipular appendages, the various modifications of leaves and stems to serve other than their normal purposes, or the different forms of leaves and flowers on the same stem, or on different plants of the same species. A collection made with some specific object in view would also be instructive, and might prove of great value; for instance, to get together examples of all the troublesome weeds of a locality for the purpose of studying their habits and devising means for their eradication; or of all the native useful plants, with detailed analyses of their economic properties, and observations on their habits and the practicability of further developing them. In short, wherever collecting is carried on, it should be done with some object other than the mere identification of species, which often results in greater detriment to the wild plants of a neighborhood than profit to the collector.

WEIGHTS, MEASURES, AND TEMPERATURES

As the metric system of weights and measures and the Centigrade appraisement of temperatures are universally employed in scientific works, the following tables showing the equivalents in our common English standards of those in most frequent use, are given for the convenience of students who have not already familiarized themselves with the subject. The values given are approximate only, but will answer for all practical purposes, except in cases where very great exactitude is required. The micron, or micrometer, is used principally by scientific investigators for measuring extremely minute objects seen under the microscope.

MEASURES OF LENGTH

METRIC		ENGLISH EQUIVALENTS
Kilometer . . .	km.	$\frac{5}{8}$ of a mile.
Meter	m.	39 inches.
Decimeter . . .	dm.	4 inches.
Centimeter . .	cm.	$\frac{2}{3}$ of an inch.
Millimeter . . .	mm.	$\frac{1}{25}$ of an inch.
Micron.	μ	$\frac{1}{25000}$ of an inch.

CAPACITY

Liter	l.	61 cubic inches, or 1 quart, U.S. measure
Cubic centimeter	cc.	$\frac{1}{16}$ of a cubic inch.

WEIGHT

Kilogram . . .	kg., or kilo.	2 $\frac{1}{2}$ pounds.
Gram	gm.	15 $\frac{1}{2}$ grains avoirdupois. $\frac{1}{28}$ of an ounce avoirdupois.

TEMPERATURE EQUIVALENTS

The next table gives the Fahrenheit equivalent, in round numbers, for every tenth degree Centigrade from absolute zero to the boiling point of water. To find the corresponding F. for any degree C., multiply the given C. temperature by nine, divide by five, and add thirty-two. Conversely, to change F. to C. equivalent, subtract thirty-two, multiply by five, and divide by nine.

Cent.	Fahr.	Cent.	Fahr.
100	212	0	32
90	194	- 10	14
80	176	- 20	4
70	158	- 30	- 22
60	140	- 40	- 40
50	122	- 50	- 58
40	104	- 100	- 148
30	86		
20	68		
10	50		
		Absolute zero.	
		- 273	- 459

INDEX

(The numbers, unless otherwise designated, refer to sections.)

- Aborted, 220, 291.
- Absorption, 58, 71, 72 ; Exp. 39.
selective, 60.
- Accessory buds, 158.
- Accessory fruits, 302.
- Adaptation, 206, 237.
- Adhesive fruits, 20; Exp. 20.
- Adjustment of leaves, 196-202.
- Adnate, 374.
- Adventitious buds, 65, 158.
- Adventitious roots, 37, 83.
- Æcidium, 362.
- Aëration, 319.
- Aërial roots, 88.
- Aggregate fruits, 301, 303.
- Air space, 114, 116, 184.
- Akene, 234, 296, 302, 305.
- Albumin, 3.
- Albuminous, 56.
- Albuminous seed, *i.e.*, containing endo-
sperm; Field work, p. 28.
- Aleurone, 3.
- Algæ, 333, 336-342.
- Alternate leaves, 168.
- Alternation of generations, 395, 400, 409,
414.
- Analogous, 108.
- Anatropous, Fig. 26.
- Angiosperms, 15, 18 ; Fig. 514.
- Annuals, 91.
- Annulus, 372, 405.
- Anther, 213, 235; Figs. 270-274.
- Antheridia, 389, 394, 398, 407.
- Antheridial, 388.
- Antherozoids, 389, 392, 395, 416.
- Antisepsis, 355.
- Arch of the hypocotyl, 42, 44.
- Archegonia, 390, 394, 407, 408.
- Archegonial, 388.
- Archegoniates, 408, 416.
- Archegonium, 391, 394, 398.
- Asexual generation, 395, 399, 409, 416.
- Asexual reproduction, 394, 395.
- Asexual spore, 395, 407, 409, 410, 416.
- Assurgent, 95.
- Axial placenta, 216, 300.
- Axil, 100, 166.
- Axillary buds, 145.
- Axis, 64, 65, 79, 152, 156, 159, 161.
- Bacillus, 348, 349.
- Bacteria, 333, 347-353.
- Bark, 118, 119, 122.
- Basidia, 375.
- Bast, 116, 119, 122.
- Berry, 291.
- Biennial, 92.
- Bilabiate, 237, 243.
- Bilateral regularity, 219.
- Bilateral zonation, 326.
- Black rust, 360.
- Blade of leaf, 165.
- Biogenetic law, 253.
- Biological factors, 309.
- Bordered pits, 114, 117 ; Fig. 123.
- Boreal, 329.
- Bract, 161.
- Bryophytes, 334, 385-401.
- Bud scales, 147-149.
- Buds, 145, 155-158.
- Bulb, 107.
- Button (of mushroom), 370.
- Calyptra, 399.
- Calyx, 211.
- Cambium, 115, 116, 120, 123.
- Cap, 372, 373.
- Capillarity, 136; Exp. 53.
- Capitate, 220.
- Caprification, 279, 305.
- Caprifig, 279.
- Capsule, 298.
- Carbon, 27, 28, 62.
- Carbon dioxide, 29, 63, 185, 186, 187, 189;
Exps. 23, 25.
- Carpels, 216, 288.
- Caruncle, 13.
- Catkin, 161.
- Caulicle, 46.
- Cedar apples, Fig. 456.
- Cell, 6, 7.
collecting, 184.
companion, 114.
- Cell sap, 7, 110.
- Cell wall, 7, 183.
- Central cylinder, 67.
- Central placenta, 216, 300.
- Chalaza, 13.
- Chlorophyll, 186, 341, 366.

- Chlorophyll bodies, 184, 186, 382.
 Cion, 65.
 Classification, 90, 252, 283, 343, 384, 411, 417.
 Cleistogamic flowers, 272.
 Climatic zones, 329.
 Climbing stems, 96-98.
 Clipped seed, p. 12 (material).
 Closed bundle, 114.
 Close-fertilized, 272.
 Cluster cups, 362.
 Coccus (pl. cocci), 339, 348.
 Coiled inflorescence, 162.
 Collective fruits, 304.
 Colony, 316, 337, 357.
 Color of flowers, 276.
 Compass plants, 199.
 Complete flower, 219.
 Composite, 235, 381.
 Composite flower, 236.
 Compound leaf, 178.
 Conduplicate, Figs. 159, 160.
 Confluent, 404.
 Conifers, 117, 327.
 Conjugation, 342, 394.
 Corolla, 211.
 Cortex, 64, 115, 122.
 Corymb, 161.
 Cotyledon, 11, 12, 18.
 Cross cut, 133.
 Cross fertilization, 255.
 Cross pollination, 255.
 Crustaceous lichen, 384.
 Cryptogam, 332.
 Crystalloids, 60.
 Culture medium, 347; p. 306 (material).
 Cycle, 217, 219, 229.
 Cycle of growth, 50.
 Cyme, 162.
 Cymose inflorescence, 162.
 Cypress knees, 319.
 Deciduous, 203.
 Declined, 95.
 Decurrent, 374.
 Definite annual growth, 153.
 Definite inflorescence, 160, 162.
 Dehiscent fruits, 283, 298.
 Deliquescent, 144.
 Determinate growth, 153.
 Determinate inflorescence, 160, 162.
 Diadelphous, 239.
 Diastase, 9.
 Dichogamy, 269.
 Dichotomous, 152; Fig. 155.
 Dicotyl, 42, 115, 116, 171; 220.
 Dicotyledonous, 12.
 Differentiate, 245, 345, 409.
 Diffusion, 9, 57.
 Digestion, 9.
 Dimorphic, 270.
 Dimorphism, 270.
 Dimorphous, 270.
 Dicecious, 268.
 Disinfection, 355.
 Disk flower, 233.
 Dispersal of seed, 19-25.
 Dominant, 257, 258.
 Dormant buds, 157.
 Dorsal; Figs. 390, 391.
 Drupe, 292.
 Dry fruits, 283, 293-300.
 Duct, 67, 111, 114.
 Ecological factors, 310.
 Ecology, 266, 308, 310.
 Edgings, 134.
 Egg cell, 251, 391.
 Elaters, 393.
 Embryo, 11.
 Embryology, 253.
 Embryo sac, 251.
 Endodermis, 67 (b).
 Endosperm, 11, 13, 14, 16, 17, 414.
 Epicotyl, 45, 46, 47.
 Epidermis, 64, 115, 122, 183.
 Epigynous, 225, 230.
 Epiphyte, 87, 394.
 Essential constituents, 62.
 Essential organs, 212.
 Evolution, 242, 245, 265, 334, 335, 401, 414, 415, 417, 418, 419.
 Evolutionary, 253, 413.
 Excentric attachment, 372.
 Excurrent, 144, 154.
 Factors, 54, 265, 310.
 Fall of the leaf, 203.
 Fascicled roots, 80, 81.
 Fats, 1, 3, 4.
 Feather-veined, 172.
 Ferments, 9, 356.
 Fertile, 404.
 Fertile flower, 267.
 Fertilization, 247, 251, 252, 392, 408, 416.
 Fibrous roots, 37, 78, 80, 81.
 Fibrovascular bundle, 67, 114, 116, 176, 288.
 Fig wasp, 279.
 Filament of the stamen, 213; a hairlike appendage, 341, 361, 369, 393, 396.
 Filamentous algae, 340, 341.
 Fission, 338, 394.
 Fleshy fruits, 283, 288-292.
 Floral envelopes, 211.
 Foliaceous lichen, 379, 384.
 Follicle, 298.

- Forestry, 139-142.
 Forked stems, 152.
 Formation, 316.
 Free, 218, 374.
 Free central placenta, 216.
 Free gills, 374.
 Free ovary, 216.
 Free veining, 402.
 Freezing, 33.
 Frog's spit, 340.
 Frond, 402.
 Fruit, 282.
 Fruticose lichen, 384.
 Function, 41.
 Fungi, 333, 343, 344, 345, 346, 378.
 Fungus, 86, 364.

 Gametes, 394.
 Gametophyte, 394, 395, 396, 406, 407.
 410, 412, 414, 415, 416.
 Gemmæ, 387.
 Generative cell, 249, 416.
 Geophilous, 321.
 Geotropism, 51, 52, 53.
 Germ, 2, 11.
 Germ cell, 251, 414.
 Germination, 32, 35; Exps. 25, 26-29.
 Germs, 352, 355.
 Gills (of mushroom), 374.
 Girdling, 131.
 Glutin, 3.
 Gourd, 14, 290.
 Grain, 11, 297.
 Grain of timber, 133, 134, 135.
 Gravity, 52.
 Growth, 48-52, 179.
 Guard cell, 183.
 Gymnosperms, 15, 18, 117, 414.
 Gymnosporangium, Fig. 456.

 Halophyte, 317, 323.
 Haustoria, 85.
 Hay bacillus, 348, 349.
 Head, 161.
 Heartwood, 131.
 Heliotropic, 200.
 Heliotropism, 198.
 Herbaceous, 90, 94, 115, 116.
 Heredity, 264, 265.
 Hilum, 12, 13, 14.
 Homologous, 108.
 Host plant, 85.
 Humus, 75, 86.
 Hybrid, 256.
 Hybridization, 256, 257, 263.
 Hydrophytes, 317, 318, 319.
 Hymenium, 375.
 Hymenomyces, 375.
 Hyphæ (sing. hypha), 369, 380.

 Hypocotyl, 11, 12, 14, 46.
 arched, 42, 44.
 straight, 44.
 Hypogynous, 218, 225.

 Imbibition, 136.
 Imperfect flower, 219, 231, 267.
 Impure hybrid, 258, 259.
 In-breeding, 254.
 Incomplete flower, 219.
 Incubation, 354.
 Indefinite annual growth, 153.
 Indefinite inflorescence, 160, 161.
 Indefinite number of parts, 229.
 Indehiscent fruit, 283, 294.
 Indeterminate growth, 153.
 Indeterminate inflorescence, 160, 161.
 Indusium, 404.
 Inferior ovary, 221, 225.
 Inflorescence, 159.
 Insectivorous plants, 208-210.
 Internode, 46, 110; Exp. 35.
 Invasion, 328.
 Inverted seed, 14.
 Involucre, 161, 232.
 Involute, 373; Fig. 251.
 Iodine solution, Exp. 3.
 Irregular flower, 219, 237.
 Irritability, 201.

 Joint, 110, 113.

 Keel, 238.
 Knots, 137.

 Lamina, 209.
 Laminæ, 368, 374.
 Lateral, 372, 398.
 Lateral buds, 145.
 Leaf attachment, 167.
 Leaf cups, 202.
 Leaf scars, 146.
 Leaf traces, 146.
 Legume, 299.
 Lenticels, 106, 118, 288.
 Lichen, 379.
 Life cycle, 359, 364.
 Loam, 75.
 Lobing, 177; Figs. 210-212.
 Locule, 216.
 Loment, Fig. 394.
 Lysate, Fig. 197.

 Medulla, 119, 122.
 Medullary rays, 64, 116, 121, 122, 134, 135.
 Megasporeangia, 409.
 Megaspore, 409, 414.
 Mendel's law, 258.
 Mesophyte, 317, 324.

- Metabolism**, 193.
Microbe, 351, 355.
Micrococcus, 339.
Micropyle, 12, 13, 14, 15, 45.
Microsporangia, 409.
Microspore, 409, 414.
Midrib, 172.
Mixed forest, 139, 324.
Modification, 100–108, 206, 207, 289.
Molecule, 136.
Monadelphous, 239.
Monocotyl, 110, 112, 171, 217, 221, 418.
Monocotyledonous, 11.
Monœcious, 268.
Monopetalous, 211.
Monosepalous, 211.
Morphology, 108.
 of the flower, 244.
Mosaic (leaf), 197.
Mosses, 334, 396–401.
Muck, 75.
Multiple fruit, 304, 305.
Mushroom, 333, 367.
Mutation, 264.
Mycelium, 343, 359, 369.
Mychorrhiza, 86.

Neck canal, 391.
Net-veined, 171.
Neuter, 267.
Neutral flower, 231, 267.
Nitrogen, 62, 63, 188.
Nitrogenous food, 188.
Node, 46, 65, 110, 113.
Nucleus, 7, 341.
Numerical plan, 217, 229.
Nut, 295.
Nutrient, 3, 186.
Nutrition, 50, 54, 179, 193.
Nyctitropic, 200.

Obsolete, 220.
Oil, 1, 3, 8.
Oöspore, 393, 394, 395.
Open bundle, 116.
Operculum, 399.
Opposite leaves, 168.
Organ, 41.
Organic foods, 4.
Organs of reproduction, 40.
 of vegetation, 40.
Osmosis, 56, 57.
Ovary, 214, 216, 223.
Ovule, 216.
Oxidation, 27; **Exps.** 21, 22.
Oxygen, 62, 63, 186, 187; **Exps.** 22, 66.

Palisade cells, 184.
Palmate veining, 172.

Panicle, Fig. 171.
Papilionaceous, 237, 238.
Pappus, 234.
Parallel veining, 171.
Paraphyses, 375, 398.
Parasitic, 5, 345, 364.
Parasitic plants, 85, 343, 382.
Parenchyma, 110, 114, 115.
Parietal, 216.
Pathogenic, 352, 353.
Pedicel, 159.
Peduncle, 159, 288.
Pentamerous, 229.
Pepo, 290.
Perennial, 93.
Perfect flower, 219.
Perianth, 211.
Pericarp, 288.
Perigynous, Figs. 301, 302.
Persistent, 166.
Petals, 211.
Petiole, 165.
Phanerogams, 331, 332.
Phloem, 114, 116.
Photosynthesis, 186, 192, 193.
Phototropism, 195.
Phyllotaxy, 168, 169.
Pileus, 373.
Pinna, 402.
Pinnate veining, 172.
Pinnule, 402.
Pioneer plant, 316, 319, 320.
Pistil, 212, 214, 223, 228, 240.
Pistillate, 267.
Pitcher plant, 209.
Pith, 110, 115, 116, 119, 121, 122.
Pitted ducts, 114.
Placenta, 216, 288, 298, 300.
Plant society, 316.
Plasmolysis, 59.
Pleurococcus, 337.
Plicate, 155.
Plumule, 11, 12, 14, 45, 46.
Pod, 298.
Pollen, 213.
Pollen grains, 213.
Pollen sac, 213.
Pollen tubes, 249, 250.
Pollination, 215, 247.
Polycotyledons, 15, 45.
Polymorphic, 365.
Polymorphism, 365.
Polypetalous, 211.
Polysepalous, 211.
Pome, 288.
Prefoliation, 155.
Primary, 396.
Primary root, 42, 79.
Pronuba, 278.

- Prostrate, 95.
- Protection, 199, 204, 207, 280, 287.
- Proteins, 3, 8, 33, 188, 204.
- Prothallium, 407.
- Protonema, 396.
- Protoplasm, 6, 7, 67, 110, 116.
- Pteridophytes, 335, 411, 412.
- Puccinia, 360.
- Pure dominant, 258, 259.
- Pure forest, 139, 324.
- Pure recessive, 258, 259.
- Pycnidia, 363.

- Quartered cut, 135.

- Raceme, 161.
- Rhachis, 178.
- Radial section, 132, 135.
- Radicle, 46.
- Rhaphe, 13.
- Ray, 161, 391.
- Ray flowers, 231.
- Receptacle, 211, 288, 289, 388, 390, 393.
- Recessive, 257, 258.
- Red rust, 359.
- Regular flower, 219.
- Reproduction, 338, 351, 358, 383.
- Respiration, 30, 31, 191, 192.
- Resting spore, 338, 342, 358, 394.
- Reticulation, 172, 402.
- Retrogressive evolution, 418.
- Revolute, 373, 404.
- Rhizoids, 379, 386.
- Rhizome, 105.
- Ring, 127.
- Rings of growth, 122, 123, 134, 135.
- Rogue, 260.
- Root cap, 39.
- Root hairs, 38, 67.
- Root pressure, Exp. 49.
- Root pull, 69.
- Rootstock, 105.
- Root system, 89.
- Root tubercles, 63, 309.
- Rosette, 197.
- Rotation of crops, 24, 327.
- Runner, 95.

- Samara, 296.
- Sap movement, 125, 126, 128, 129.
- Saprophyte, 86.
- Sapwood, 131.
- Scale leaves, 101, 106, 107, 147-149, 207.
- Scape, 107, 159.
- Scorpioid inflorescence, 162; Figs. 173-176.
- Screenings, 20; p. 28, Qn. 22.
- Secondary roots, 37, 42, 79.
- Seed, 11-18, 332, 415.
- Seed coat, 12, 14, 15, 43.
- Seedless fruits, 285, 286.
- Seedlings, 36, 42, 43, 45.
- Seed plants, 331, 414.
- Seed vessel, 282.
- Selection, 260, 265, 286.
 - artificial, 262.
 - natural, 261.
- Self-fertilization, 254, 271.
- Sepals, 211.
- Sessile, 167, 214.
- Seta, 399.
- Sexual generation, 395, 396, 406, 410, 416.
- Sexual reproduction, 394, 395, 410.
- Sheath, 67, 116.
- Shrinking of timber, 136.
- Sieve tube, 114.
- Slabs, 134.
- Sleep movements, 200.
- Soils, 75, 77.
- Sori, 404.
- Spathe, 221.
- Specialization, 237.
- Spermatophytes, 331, 335, 394, 414.
- Spermatozoid, 389.
- Spermogonia, 363.
- Spike, 161.
- Spirillum, 348.
- Spirogyra, 341.
- Sporangia, 390, 405.
- Spore, 332, 349, 350, 377, 406, 410.
- Spore case, 390, 393, 405.
- Spore print, 376.
- Sporidium, 361.
- Sporogonium, 393, 399.
- Sporophyll, 406, 414.
- Sporophyte, 393-395, 399, 406, 410, 412, 414, 416.
- Sport, 264.
- Stamen, 212, 213.
- Staminate, 267, 268.
- Staminodia, 244.
- Standard, 238.
- Starch, 3, 4, 187, 204, 288; Exps. 69, 70.
- Stems, 90-99.
- Sterile flower, 267.
- Sterilization, 354.
- Stigma, 214.
- Stigmatic surface, 223.
- Stimulus, 98, 186, 201.
- Stipe, 240, 372, 402.
- Stipule, 149, 165, 166.
- Stolon, 95.
- Stoma, 181, 182, 183.
- Stomata, 181, 182.
- Stone fruit, 292.
- Storage of food, 2, 3, 4, 17, 70, 103, 104-107, 287.
- Strangling fig, 88.

- Strobile, 411.
 Strobiliaceous, 411.
 Style, 214.
 Succession, 327.
 Sugars, 3, 4, 204, 288.
 Summer spores, 360.
 Sundew, 210.
 Superior ovary, 218, 221, 225.
 Supernumerary buds, 158.
 Suppressed, 220.
 Survival of the fittest, 261.
 Suture, 216, 298, 299.
 Swarm spore, 349.
 Swelling of timber, 136.
 Symbiosis, 309, 382.
 Symmetrical flower, 219.
 Sympetalous, 211.
 Syncarpous, 300.
 Synsepalous, 211.
 Systematic botany, *see* Appendix.

 Tangential cut, 132, 134.
 Tap root, 79.
 Teleutospore, 360.
 Tendril, 96, 97.
 Terminal bud, 145, 154.
 Testa, 14.
 Thallophytes, 333.
 Thallus, 333, 341, 343, 379, 380, 381, 385.
 Tillage, 76.
 Tissue, 60, 61.
 Toadstools, 367.
 Toxins, 345.
 Tracheids, 114, 117.
 Trailing, 95.
 Trama, 375.
 Transpiration, 179, 180.
 Trifoliate, Figs., 215, 216.
 Trimerous, 217.
 Trimorphic, 270.
 Tuber, 106.
 Tumbleweeds, 23.
 Turgidity, 7.
 Turgor, 179.
 Twining, cause of, 98; Exp. 55.
 Twining stems, 96; Exp. 54.
 Type, 18, 260, 263, 265, 336, 411.

 Umbel, 161.
 Umbonate, 473.
 Underground stems, 104-107.
 Unicellular, 337.
 Unisexual, 267.
 Uredo, 359.
 Uredospore, 359, 360.

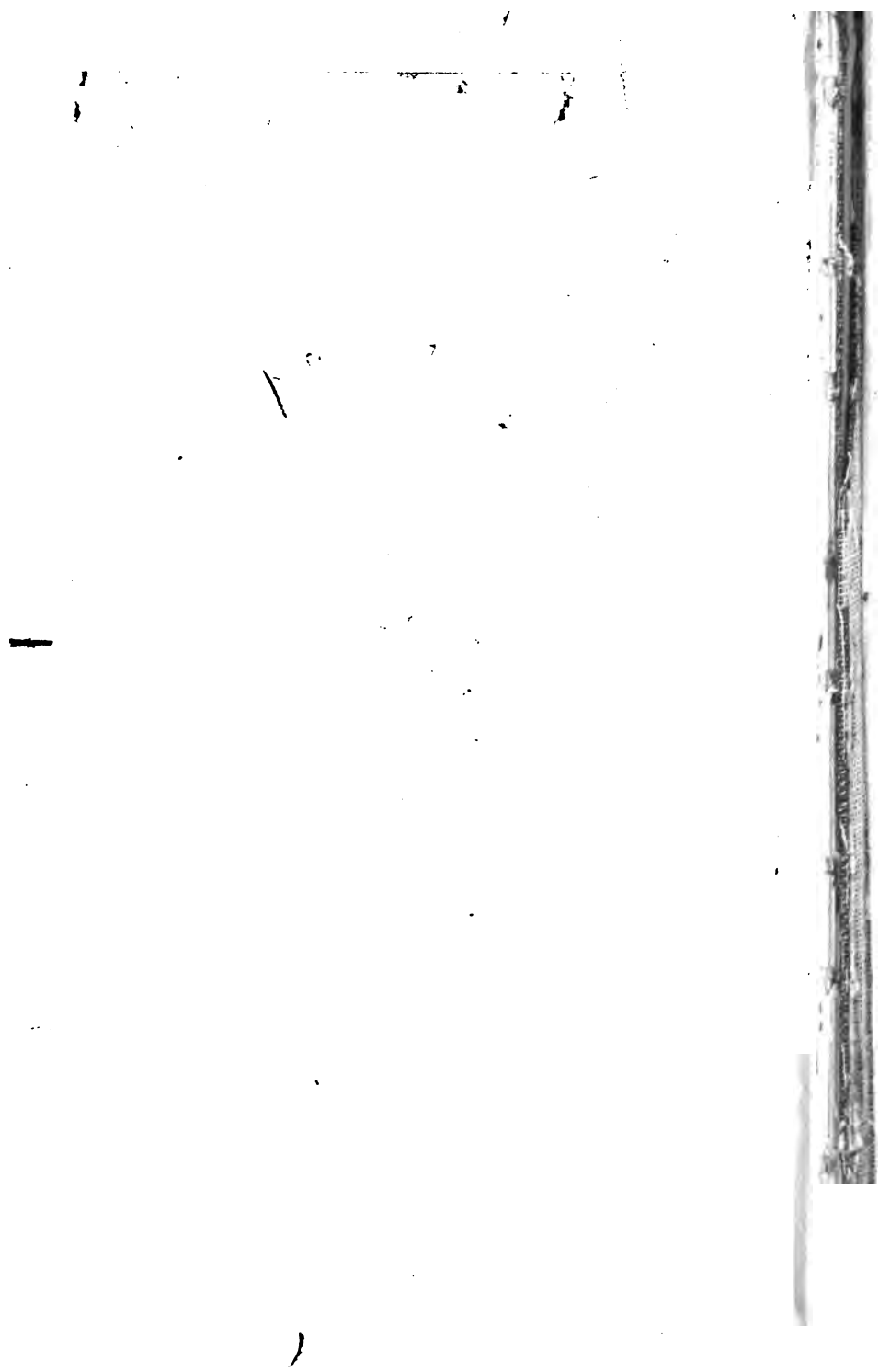
 Variation, 263, 264, 265.
 Vascular bundles, 111.
 Vascular cryptogams, 403, 411, 412.
 Vascular cylinder, 64.
 Vascular system, 111, 113, 335.
 Vegetative reproduction, 358.
 Veil, 371.
 Veins, 173-176.
 Venter, 391.
 Ventral, Figs. 390, 391.
 Vernation, 155.
 Vessels, 111.
 Vexillum, 238, 239.
 Vibrio, 348.
 Vitality of seeds, 34; Exp. 30.
 Volva, 371.

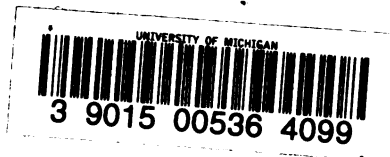
 Water roots, 39, 84.
 Whorled leaves, 168.
 Wind pollination, 274, 275.
 Wings, 238.
 Winter spores, 360.

 Xerophyte, 317.
 Xerophyte societies, 317, 320-322.
 Xylem, 114, 116.

 Yeast, 356.
 Yeast colony, 357.
 Yellow trumpets, 209.
 Yucca, 278.
 Yucca moth, 278.

 Zonation, 325, 327.
 bilateral, 326.
 concentric, 326.
 horizontal, 326.
 vertical, 326.
 Zones of vegetation, 325.





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